Forest resources assessment 1990

Survey of tropical forest cover and study of change processes

Technical report of
a major global cooperative effort
coordinated by the
Forest Resources Assessment 1990 Project

FO: GCP/INT/475/NET
FO: GCP/INT/501/FIN
FO: GCP/INT/544/SWE
FO: GCP/INT/550/USA
FO: GCP/RAF/281/EEC
FO: TCP/RAF/2261

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M-35
ISBN 92-5-103808-2

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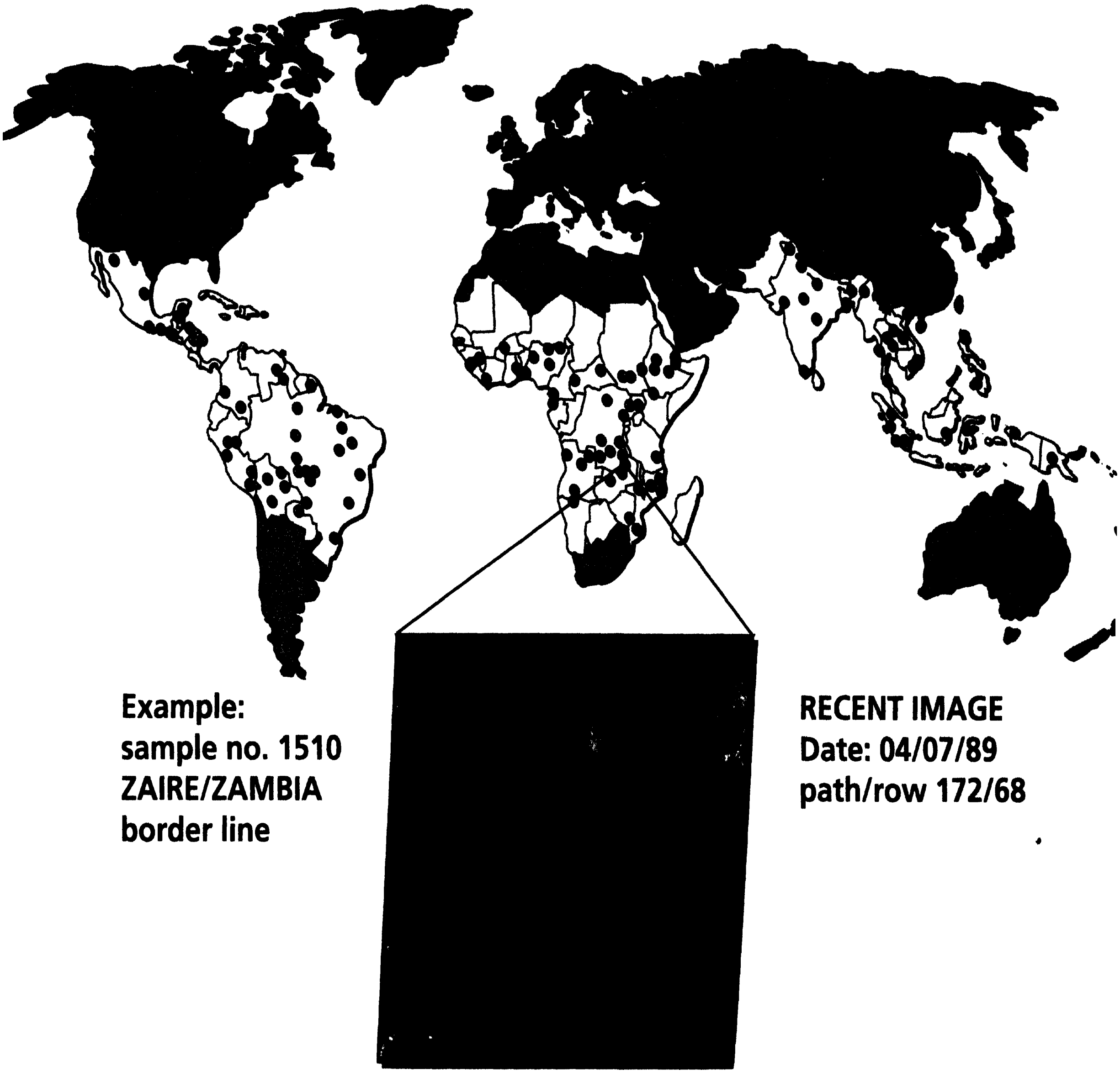
Pan-tropical continuous forest resources survey design

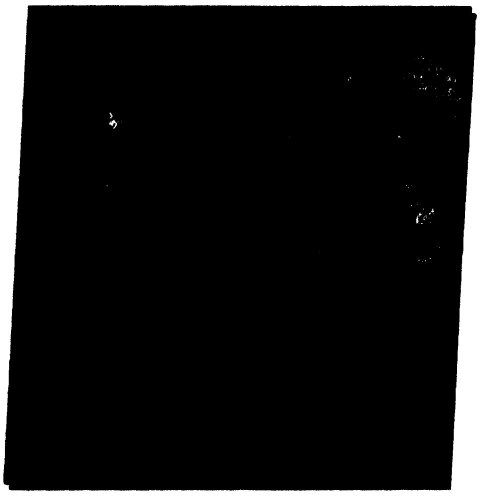


Example:
sample no. 1510
ZAIRE/ZAMBIA
border line

RECENT IMAGE
Date: 04/07/89
path/row 172/68

HISTORICAL IMAGES

Date: 13/06/81 P/R 185/68



Date: 20/07/79 P/R 184/68

Foreword

For nearly 50 years (1946 - 1990), the FAO has routinely assessed the state of the world's forest cover. These assessments have provided some of the most comprehensive and useful information available regarding the world's forests. This information is in great demand by scientists, practitioners and decision-makers.

In order to increase reliability and better respond to information needs, the 1990 Forest Resources Assessment utilized a two-phased approach. The first phase of the assessment was made using existing national forest inventories and maps in conjunction with an adjustment model used to standardize the results to a common reference date. Information on the methodologies and results of the first phase are available in Forestry Paper N°112 (Forest Resources Assessment 1990: Tropical Countries). The second phase of the 1990 assessment was conducted in the tropical zone only and employed a statistical survey using remote sensing to sample the forest cover.

The approach for the second phase was based on the comparison of satellite imagery from two dates by the same analyst at the same time, using a uniform classification throughout the tropics. By using this approach, class to class changes in land cover could be detected and depicted in change matrices according to regions and climatic zones. Information on class to class changes is new and adds substantially to the understanding of the processes of vegetation degradation and deforestation. Statistical estimates of the standard error were also generated and used to compare the results derived from existing inventory data (first phase) to those based on remote sensing (second phase). This report describes the methodology used in the second phase and the related findings.

The results of this work have special importance as they demonstrate that the state of forest cover for 1990 and the rate of change from 1980 to 1990 estimated by the two phases lie within the confidence interval established from the sample survey data (second phase). Consequently, concerns regarding the consistency and reliability of global forest resources assessments were addressed for the first time. The results of the remote sensing sample survey do not replace the forest cover state and change data published in Forestry Paper N°112, but confirm them and complement them by providing a new wealth of information on the processes of forest change.

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Acknowledgements

The survey of tropical forest resources was supported by the Governments of Finland, the Netherlands, Sweden and the United States (through U. S. Forest Service) as well as the European Union through a multi-donor trust fund. Personnel assistance was given through the Associate Professional Officers scheme of the Governments of Germany, the Netherlands, Sweden and the United States. Regional workshops on forest monitoring methodology with the participation of representatives from some forty tropical countries, were supported by the Unit of Technical Cooperation among Developing Countries of the United Nations Development Programme (Bangkok, 1991), by the U. S. Forest Service (Nairobi, 1991, and Mexico City, 1993), by the European Community and FAO Technical Cooperation Programme (Yaounde, 1994).

Major in-kind contributions were made by cooperating institutions including the U.S. Forest Service, the Swedish University of Agricultural Sciences, the University of Freiburg, Germany, and the Overseas Agronomic Institute, Florence, Italy. The Environmental Protection Agency of USA (EPA) provided a grant for acquiring historic satellite images for all the tropical zone and the National Research Council of Thailand provided satellite data of south-east Asia for shifting cultivation studies.

The Forest Resources Assessment 1990 Project, located at FAO, Rome, was conducted by a project team led by Dr. K.D. Singh, who conceived the sample survey design on the lines of continuous forest inventory technique and secured necessary resources and collaboration for its implementation.

Mr. R. Drigo made a major contribution to the remote sensing component of the survey including development and dissemination of the interdependent image interpretation technique, review of interpretation for all sampling units, study of change processes and writing the present report.

Dr. R. Czaplewski and Professor B. Ranneby made important contributions to the statistical survey design and analytical models, and Professor D. R. Pelz led a IUFRO review of the design.

Mr. M. Lorenzini developed the Project's Geographic Information System and, in cooperation with Mr. A. Marzoli and Mr. G. Mu'Ammar contributed to the definition and stratification of the sampling universe through the combined analysis of geographic and database information.

Mr. A. Hildeman and Mr. H. Simons significant contribution to the dissemination of the monitoring methodology through the organization of regional workshops and training sessions.

Mr. R. Baltaxe contributed to the development of the monitoring methodology and provided useful comments to the present report.

Ms. E. Milani contributed to the production of the various maps that are shown in the present report on the basis of the Project's Geographic Information System.

Ms. C. Hardy and Ms. J. Rechter contributed to the preparation of the present report through proof reading and language editing.

In addition, the survey benefited from the collaboration with an extended network of institutions and individuals, remote sensing centers, and participants to the regional workshops, who all contributed in the interpretation of remote sensing images, by providing source information, consultancies and expert help. The Forest Resources Assessment 1990 Project is greatly indebted toward this large number of contributors that made this challenging idea possible and successful.

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Abbreviations

ASCII	American Standard Code for Interchange of Information
AVHRR	Advanced Very High Resolution Radiometer (instrument of NOAA satellites)
COFO	Committee on Forestry
EC	European Community
EDC	Eros Data Center of the US Geological Survey
EOSAT	Earth Observation Satellite Company
FAO	Food and Agriculture Organization of the United Nations
FORIS (1990)	Forest Resources Information System (baseline 1990)
FRA 1990	Forest Resources Assessment 1990 Project
FSI	Forest Survey of India
GAC	Global Area Coverage (AVHRR data at 4 km resolution)
GIS	Geographic Information System(s)
HRSD	High Resolution Satellite Data
IAO	*Istituto Agronomico per l'Oltremare* (Overseas Agronomic Institute), Florence, Italy
IBAMA	*Instituto Brasileiro de Meio Ambiente e Recursos Naturais Renováveis*, Brazil
IBM	International Business Machines
INPE	*Instituto Nacional de Pesquisas Espaciais*, Brazil
IUCN	International Union for the Conservation of Nature (The World Conservation Union)
LAC	Local Area Coverage (AVHRR data at 1 km resolution)
MSS	Multi-Spectral Scanner (sensor of Landsat satellites)
NASA	National Aeronautics and Space Administration (United States of America)
NOAA	National Oceanic and Atmospheric Administration
RS	Remote Sensing; used also to indicate the remote sensing component of the FRA 1990 Project
SPIAF	*Service Permanent d'Inventaire et d'Aménagement Forestiers*, Zaire
SU	Sampling Unit
SUAS	Swedish University of Agricultural Sciences
TCDC	Technical Cooperation among Developing Countries
TM	Thematic Mapper (sensor of Landsat satellites)
TREES	TRopical Ecosystem Environment observations by Satellites; joint project of the Commission of the European Community
UN	United Nations
UNCED	United Nations Conference on Environment and Development (Rio de Janeiro, Brazil, June 1992)
UNEP GRID	United Nations Environment Programme - Global Resources Information Database
USFS	United States Forest Service
WRS (1 or 2)	World Reference Systems (1 or 2) of the Landsat Programme

Executive Summary

Objectives

The survey of tropical forests reported here was developed and implemented with the aim of providing detailed and reliable information on the process of on-going changes in the tropical forest cover, in order to meet the needs of researchers, policy makers and the public at large. It addresses the following types of questions:

- How are the tropical forest resources changing?
- How much is being degraded? Fragmented?
- What is happening to deforested land?
- How are forest state and change linked with ecological and socio-economic conditions?
- What are the causes of deforestation?

The only satisfactory way to provide reliable information on the process of change is to establish a forest resources monitoring system, using a globally compatible and consistent methodology. This provides reliable and location specific change information. In consideration of cost, precision and timeliness of results, a sampling approach based on remote sensing was designed and used to cover the entire tropical belt.

The specific objectives of the survey were:

1. to achieve the highest possible level of consistency and precision in the assessment of forest cover state and change at global and regional levels;
2. to develop and disseminate a simple and robust monitoring technique for producing the forest cover state and change estimates at global and regional levels with application also at national level; and,
3. to provide spatial and statistical data for estimating class to class changes of land cover and forest cover categories between the two dates of interpretation at the sample locations and for producing change matrices at regional and global levels.

Though applied only in the tropical zone, the survey methodology is general and can easily be applied worldwide for all the forest formations to provide reliable information on the extent and the process of change on a consistent and continuing basis.

Methodology

The survey covers all the tropical regions. The World Reference System 2 (WRS2) of the LANDSAT satellites is used to construct the sampling frame. LANDSAT scenes covering approximately 3.4 million hectares serve as sampling units.

In view of cost-benefit considerations, the sampling units have been selected from all LANDSAT scenes with a minimum land area of 1 million hectares and a forest cover of 10 percent or more, estimated on the basis of existing vegetation maps. This has restricted the area surveyed to some 62 percent of the total tropical land area but containing some 87% of the total tropical forest.

The main characteristics of the survey design are as follows:

- It covers the entire range of woody vegetation formations in the tropics, from the rainforests of the wet zone to the shrub and tree savannas of the dry zone.
- It provides estimates of mean forest cover area and area change together with an estimate of associated error.
- It is cost-effective through use of two-stage stratification based on existing FORIS/GIS information.
- It is based on the concept of continuous forest inventory with a view to furnishing consistent estimates of mean changes over time.

This first survey round is based on a 10 per cent sample consisting of 117 sampling units randomly selected. The distribution of the selected sampling units by region is 47 in Africa, 30 in Asia and 40 in Latin America. This sample size was chosen to estimate forest cover at global level with a standard error less than ±5 percent. At each sample location, satellite images of the best quality and appropriate season, separated by an approximate ten-year interval, have been selected for observation. The image close to 1990 provides assessment of the current state; whereas the area in common between the "1990" and "1980" images provides the assessment to be made of the changes over time.

A distinctive feature of the methodology lies in the fact that it provides not only forest cover change data, but also maps and change matrices for each sample location. This enables estimations of class to class changes of land cover and forest categories between the two dates of interpretation at sample, regional and global levels: this is essential information for understanding the complex processes taking place, such as deforestation, fragmentation, degradation and afforestation.

The salient features from a remote sensing point of view are the following:

i) **Standard classification** of various forest classes (closed, open, with shifting cultivation, fragmented) on a pan-tropical basis;
ii) **Interdependent interpretation procedure**: this interpretation approach secures the highest level of thematic and spatial consistency between historical and recent image classification. This procedure is the most important element of the methodology since it reduces the error associated to the estimate of changes and makes production of change matrices possible;
iii) **Image archive:** all images used represent permanent reference as part of a continuous time series; in future these images will be used to estimate the speed of change (3 or more time series);
iv) **Low sophistication**: in spite of its sound conceptual basis, the methods and procedures developed for this survey are simple and robust and require very low technological inputs; the methodology has been designed for implementation in average developing country conditions;
vi) **Flexibility**: although applied here in a global survey context, the monitoring methodology can be applied at national or sub-national level without substantial modifications.

The interpretation was implemented at selected regional and national forestry and/or remote sensing institutions, which have a good knowledge of the sample locations and are traditionally involved in forest resources assessment activities. With the two-fold objective of strengthening national capacities for forest monitoring and improving the quality of image interpretation, the Project organized three regional workshops and eight training sessions with national institutions, benefiting 27 countries and 81 participants.

The results and quality of the interpretation undertaken by local institutions were centrally reviewed and evaluated. A database was established and analyses carried out as is presented in the following sections.

The project's Geographic Information System (GIS), with its multiple layers of geo-referenced information, has been an integral element of the survey both at the stage of survey design and at the stage of analysis of results.

Considering the extremely poor information available on the processes of change of the tropical forest resources, this project component could be considered an important achievement.

Summary of main results[1]

Estimates of forest cover and deforestation rates, with associated standard errors, have been produced, at pan-tropical and regional levels, for three different definitions of forest, in order to highlight the important effect of such definitions on the estimation of deforestation rates.

Mean pan-tropical forest cover estimates, at year 1990, range between 40.6 and 54.5 percent of land, depending on the adopted definition of forest, with associated standard errors ranging between 3.5 and 4.5 percent of the mean. Pan-tropical forest cover change estimates, in particular mean annual deforestation rates, range between 0.6 and 0.7 percent of the 1980 forest cover, with standard errors on the range of 12 to 14 percent of the means. These results met the objectives in statistical precision expected during the project's design phase. The higher error in change estimates is explained by the "event" character of change and its consequent high variance with respect to the state.

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[1] All estimates discussed in the present report refer to the fraction of the sampling frame from which the sample was selected, which represent 62 percent of the total geographical area of the tropical regions. As a consequence, these estimates cannot be directly compared to other estimates referring to the total land area.

A most interesting result of the survey is represented by its set of transition matrices, one for each Sampling Unit, that describe in detail the class-to-class changes for the ***land cover classes***. (See box)
The matrices associated with the sampling units can be aggregated at various levels following the standard statistical procedure. Mean transition matrices have been produced and subsequent change analysis has been carried out for the three regions and by three ecological zones (Wet and Very Moist, Moist, Dry).

Pan-tropical level

Closed forest is the land cover class undergoing the largest number of changes, comprising **51.6** percent of all changes observed, at pan-tropical level, over the period 1980-1990; this change in closed forest can be subdivided by destination categories, as follows:

- 20.5 percent changed into permanent agriculture, cattle ranching, water reservoirs, etc., with a complete loss of tree cover and woody biomass;
  13.5 percent into shrubs and short fallow agriculture which still represent deforestation but with some remaining woody biomass;
- 5.1 percent into fragmented forest which represents partial deforestation, with loss of approximately two thirds of the original forest cover;
- 10.2 percent into open forest or long fallow shifting cultivation which represent forms of degradation implying consistent loss of biomass (approximately half); and
- 2.2 percent into agricultural or forestry plantations.

Land cover classes

Closed Forest
Open Forest
Long Fallow
(forest affected by shifting cultivation)
Fragmented Forest
(mosaic of forest / non-forest)
Shrubs
Short Fallow
(agricultural areas with short fallow period)
Other Land Cover
Water
Plantations
(agricultural and forestry plantations)

The remaining changes occurred in **open forest** (12.1 percent of total change), **shrubs** (11.5 percent) and **fragmented forest** (8.8 percent), the rest (16 percent) being distributed among the remaining five classes. Over 90 percent of all changes are negative, implying a loss of biomass, while only 10 percent or less are positive, implying an increase of biomass.
Various changes have been observed, with varying environmental implications, which, however, cannot be described through the simplistic dichotomy *forest-deforestation*; in order to understand these complex land cover dynamics and develop effective preventive or corrective measures, detailed classifications and new analytical tools, such as change matrices and woody biomass flux diagrams, are essential.

Regional level

The detailed analysis of changes occurring shows that there is not only a quantitative difference among the three tropical regions vis-à-vis rates of change but that there are also strong regional characters in the processes of change that indicate distinctive cause-effect mechanisms.

- Forests in **Africa** show a total rate of change of 6.6 percent, manifesting almost equally all phases of negative change (*deforestation to other land cover* and *to other wooded land*, *fragmentation* and *degradation*); such changes appear to be mainly the effect of rural population pressure, characterized by the transition from ***closed forest*** to ***short fallow*** (subsistence farming) and progressive intermediate stages of depletion.
- Forests in **Latin America** show a slightly lower total rate of change: 5.9 percent, but caused almost exclusively by *deforestation to other land cover* (and therefore reaching a higher deforestation rate than Africa); this type of change appears to be the effect of centrally-planned operations such as government resettlement schemes, large-scale cattle ranching and hydroelectric schemes dominated by transition from ***closed forest*** to ***other land cover***.
- Forests in **Asia** show a much higher total rate of change: 11.3 percent, which includes, as main categories of change, *deforestation to other land cover* and *to other wooded land, degradation and conversion to plantations* (agricultural and forestry). These changes are the result of two driving forces: rural population pressure and centrally-planned operations; the former comprises the intensification and expansion of shifting cultivation practices which show transition from ***closed forest*** to ***long fallow*** and

to ***short fallow***, the latter caused by government resettlement schemes and large plantation programmes which show transition from ***closed forest*** to ***other land cover*** and to ***plantations***.

Ecological level

The analysis by ecological zone reveals important elements on (i) the intensity and distribution of forest area changes and (ii) their environmental impact. The analysis of land cover changes by ecological zone shows clearly that, in all geographic regions, the forests of the moist zone have changed, i.e., have been deforested, fragmented, degraded, etc., with much higher intensity than the forests in the wet and dry zones. The percentage of pan-tropical forest area that has changed in the period 1980-1990 is estimated at **10.1 in the moist zone** versus **4.8 in the wet zone** and **4.6 in the dry zone**. However, an indicative analysis of the biomass involved in such changes shows that, owing to the important differences in forest biomass density among the three zones and to the different change processes, the biomass loss in the wet zone is only slightly less than that lost in the moist zone and probably ten times more than that lost in the dry zone.

From the results summarized above it would appear that socio-economic and cultural factors, which are more homogeneous within geographic regions, determine the nature of forest change processes while ecological characteristics determine the intensity of change.

A comparative analysis has shown that estimates of forest cover at tropical and regional level from the FAO's **Forest Resources Information System (FORIS)**[1] are within 95 percent confidence limits of those derived from the present **remote sensing (RS) survey**, when the data sets are made consistent in respect of study area and definition of forest.

Moreover, FORIS and RS estimates of forest cover and deforestation rate at stratum level are highly correlated, which is an important requisite toward achieving the efficient integration of the two databases aimed at improving the reliability of future country-level estimates for standard reporting years, and at optimizing future RS sample survey rounds. For sake of clarity it should be stated that the RS results do not replace the forest statistics of FORIS but rather complement them, by providing information on the processes of change and insight on the cause-effect mechanisms.

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[1] Results of the Phase I of the FRA 1990 Project, published in the FAO Forestry Papers 112 "Tropical Countries" [FAO,1993], and 124 "Global Synthesis" [FAO,1995].

Chapter I

Introduction

1.1 BACKGROUND

During the past decade concern for the environment and in particular for the consequences of the depletion of natural resources has been rapidly growing in the conscience of people around the world. The fate of the forests in general, and tropical forests in particular has been receiving increasing attention owing to the far reaching consequences that deforestation and degradation have on the environment, the well-being of mankind and biological diversity.

This concern has been expressed by national and international institutions, governmental and non-governmental organizations (NGOs), opinion groups, etc.. and has resulted in innumerable resolutions, some of which have global relevance. A high point in international interest was reached at the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro (1992) which devoted a full chapter of its Agenda 21 (entitled "Combating Deforestation") to forest conservation and development and adopted the "non-legally binding, authoritative statement of principles for a global consensus on the management, conservation and sustainable development of all types of forests".

A major contributory factor to this concern for the current state of tropical forests has been the large degree of uncertainty associated with the available information on the rate of global deforestation and the total lack of quantitative information on the associated change processes.

Several related questions have been posed by policy-makers, the scientific community and the public at large. What is the area of the remaining tropical forests? At what rate are they being depleted? Is the rate of deforestation accelerating or slowing down? What are the causes? What are the ecological, economic and social effects of forest change?

Questions on global climatic change, loss of biodiversity, etc. demand both the increased precision of estimates and new types of information. Forests could be a source or a sink of global carbon depending on whether forest biomass increases or decreases; a question related closely to tropical forest depletion.

These issues called for a global deforestation assessment of a new generation. Five main requirements for the assessment technique to be developed were identified:

(i) The database used should be verifiable and the procedures of assessment objective.

(ii) The technique should have a statistical basis and provide not only mean values but also their confidence limits (e.g., mean deforestation rate and its standard error).

(iii) The procedure must provide consistent and comparable estimates over time, because deforestation is a dynamic process.

(iv) The approach must address the causes and effects of deforestation, as these have become important issues in view of global concern about the possible negative effects of deforestation and forest degradation on the CO_2 cycle, loss of biodiversity, land degradation, etc.

(v) The methodology must be easily transferable to developing countries. This would contribute to the development of sound programmes for national forest resources assessment from which the global assessments could benefit.

As clearly stated above, the assessment was to be implemented on a statistically sound basis, not only to provide reliable results but also to **provide a time-series of estimates**, of known precision, and to contribute to **knowledge about the process** of deforestation. It may be noted that consistency and continuity of assessment have implications for the **continuity of institutions** at global and national levels.

1.2 RECENT ACHIEVEMENTS IN TROPICAL FOREST RESOURCES ASSESSMENT

To meet the need for more detailed and accurate information mentioned earlier, FAO Forest Resources Assessment 1990 (FRA 1990 Project) carried out an assessment of forest resources of the tropical countries for the reference year 1990 based on **existing reliable data** (from national or sub-national forest inventories, surveys, etc.). This activity constituted Phase I of the Project.

A detailed description of the methodology used and results is given in FAO Forestry Paper 112: *Forest Resources Assessment 1990: Tropical countries (FAO, 1993)* and a summary is provided in FAO Forestry Paper 124: *Forest Resources Assessment 1990: Global Synthesis (FAO, 1995).* This assessment was implemented according to the following steps: establishment of database modelling techniques and production of standard results by country for the reference year 1990. The report covers many important forest resources parameters such as area of natural forests and plantations; forest-harvesting, land and forest area by ecological zone and the rate of deforestation during 1980-1990, by country and ecological zone.

A Forest Resources Information System (FORIS) has been developed to store and retrieve the data collected previously and new data which will become available in the future. The linkage between FORIS statistical data and geo-referenced databases, including vegetation cover, ecological zones and sub-national boundaries, has opened new opportunities for carrying out the analysis of deforestation on an ecological basis.

Forest Resources Assessment 1990 based on FORIS constitutes an important contribution to FAO global forest resources assessment; however, in view of the limitations inherent in the heterogeneity of its data sources, it does not satisfy all the requirements for the study of global change listed earlier in Section 1.1. Lack of global consistency in source data with respect to classification, reference period, scale, precision, etc., strongly reduces their suitability for the study of global changes at the required depth.

These were some of the considerations included in the development and implementation of a statistically sound survey of tropical forests based on the concept of continuous forest inventory (see Forestry Paper 112: page 8) which constitute Phase II of the Project.

This complementary approach meets all five requirements specified earlier by providing a more detailed, informative and objective description of the change processes. Moreover, its results can be easily integrated with those of FORIS within the framework of a two-phase survey approach.

The present report presents the activities and results of Phase II of the Forest Resources Assessment 1990 Project.

1.3 OBJECTIVES OF ASSESSMENT

As mentioned above, a survey was required primarily to provide a reliable estimate of tropical deforestation to international policy makers, an estimate which was not available nor possible from existing data (FAO, 1993).

An equally important reason was the scientific community's demand for a time-series of estimates for the study of global change. This called for the establishment of an assessment system capable of providing forest cover change information on a consistent and continuing basis.

Information on the processes of change was also an important motive in conducting the survey. In the context of the Tropical Forest Action Programme (formerly TFAP, now called the National Forestry Action Programme, NFAP), reliable statistics concerning the fate of deforested land were needed in order to take appropriate policy measures to control deforestation. The situation was often known in qualitative terms, but not in quantitative terms.

The only satisfactory way to provide reliable information on the processes of change is to establish a forest resources monitoring system, wherein the land area under consideration is observed on a systematic basis over time, using comparable techniques. This provides reliable and location-specific change information.

In consideration of costs, as well as the precision and timeliness of results, a sampling approach was designed and used to cover the entire tropical zone.

The specific **immediate objectives** were:

(i) to achieve the highest level of consistency and precision in the assessment of forest cover changes at global and regional levels, and to contribute to the improvement of the global forest area estimate;

(ii) to develop and disseminate a simple and effective monitoring technique for producing estimates of forest cover state and change at global and regional levels, suitable for application also at national level; and

(iii) to provide spatial and statistical data for estimating class-to-class changes of land use and forest cover categories between the two dates of interpretation at the sample locations and for producing change matrices at regional and global levels.

In order to optimize the use of the results deriving from the two phases of the Project, the first providing wall-to-wall sub-national level data and the second providing statistically reliable data on forest cover and change processes at global and regional levels, it is essential to integrate the two data sets into a unique resources assessment system. This integration, discussed in further detail in Section 6.2 could be considered as the development objective of the present remote sensing survey.

1.4 DEVELOPMENT OF THE SURVEY DESIGN

Available data

An intensive review of the literature carried out during the first phase of the Project revealed an almost complete lack of reliable data on the subject. Table (1.4) 1 below reports the level of information available from the tropical countries on forest resources state and change, in concise form. Even without analyzing the quality of the individual surveys it is clear that the data available are rather inadequate to provide reliable information on the changes occurring in the forest cover.

Table (1.4) 1: **State of forest inventory in the tropics at the end of 1990**

Region	Number of countries under assessment	Forest area information			
		No assessment	One assessment		More than one assessment
			before 1981	1981-90	
Africa	40	3	23	12	2
Asia & Pacific	17	0	1	6	10
L. America & Caribbean	33	0	15	9	9
Total	**90**	**3**	**39**	**27**	**21**

Source: FORIS database of the FRA 1990 Project

Below are some relevant comments expressed in FAO Forestry Paper 112 on the current state of the country forest inventories:

- There is considerable variation among regions with respect to completeness and quality of the information, with Asia faring better than Latin America and the latter better than tropical Africa.

- There is considerable variation in the timeliness of the information. The data is about ten years old, on average, which could be a potential source of bias in the assessment of change.

- There are some countries which have carried out more than one assessment. These countries, however, have not used appropriate techniques, such as Continuous Forest Inventory (CFI) design, for change assessment. In most cases, the surveys have been carried out independently from the previous ones and therefore present differences that are not only due to forest cover changes.

- There is little consistency among the classifications adopted in the country surveys and there seems to be little agreement even on the very concept of "forest". The effect of this poor consistency is that the global synthesis could only report on "forest area" and "deforestation" with no further breakdown.

It was on the basis of this in-depth review of the existing information that the decision was taken to carry out a statistically designed pan-tropical forest survey based on new observations.

Study of survey options

It may be appropriate to mention here that recommendations for a survey of tropical deforestation, on a statistical/remote sensing basis, date back to the United Nations Conference on Human Environment in Stockholm (1972). A FAO/UNEP (United Nations Environment Programme) Expert Consultation, in 1974, conducted an in-depth study of the subject and drafted specific proposals for tropical forest cover monitoring. During 1978-1982, FAO/UNEP jointly carried out pilot studies on forest cover monitoring in the West Africa Region, covering Benin, Togo and Cameroon (Baltaxe, 1980).

In forestry practice, techniques known as Continuous Forest Inventory (CFI) and permanent sample plot (PSP) have been used for several decades. The challenge was to synthesize these ideas and develop a system of forest cover change monitoring based on statistically sound principles in an economically feasible and globally practical way. The possibility of procuring repetitive coverage of the earth's surface from remote sensing satellites provided a unique opportunity for this purpose.

A Project paper, "Analysis of Alternative Sample Survey Designs", by R. Czaplewski describes the alternative designs considered, and the process used to select the present design. The four design alternatives considered were:

1. Wall-to-wall collection of existing data, primarily national forest inventories, supplemented with regression models that predict rates of deforestation as functions of eco-floristic classifications and human population density.
2. Wall-to-wall digital classification of coarse resolution satellite scenes of 1990. All terrestrial 1.1 km^2 AVHRR pixels for the world's tropics are classified into two categories: *forest* and *non-forest*. Regression models from the first alternative would be used to estimate the rate of deforestation between 1980 and 1990.
3. Visual interpretation of a randomized sample of high resolution satellite images from 1980 and 1990 (which are treated as permanent plots), with a sampling intensity of 5 to 40 percent of the world's tropics. All 30m pixels within each sample scene are classified into 7 to 14 different categories of terrestrial cover.
4. Wall-to-wall visual interpretation of high resolution satellite images from the year 1980, repeated for the year 1990.

The choice between census (i.e. wall-to-wall coverage) and sampling was an important issue. A sample survey, as is well known, is associated with a sampling error, but has advantages if the area to be covered is large or observations are to be made on a repetitive basis. A wall-to-wall coverage, on the other hand, has no sampling error though it may have larger observation or non-sampling errors, in view of the extensive rather than intensive approach, and it costs more.

At national level it is feasible and even desirable to organize wall-to-wall forest mapping at suitable intervals of time; but, at global level the logistics involved are complex and the costs very high. For the present project, with limited funding and time, it was obvious from the very beginning that sampling would be the only way to proceed. The most important consideration was to minimize the sampling error by utilizing all the existing information and available knowledge on sampling techniques.

Review of past experience

A literature review was conducted to identify techniques of forest cover monitoring using remote sensing. Most techniques were based on a comparison of area information from independently compiled maps of two or more dates prepared in the following manner: a full set of cloud free images covering the whole study area was acquired and interpreted. The interpreted details were transferred to base-map(s). This thematic map was then used to compile area information manually or digitally. The difference between forest cover area from the two or more sets of compiled maps, divided by the time interval between them, provided an estimate of the rate of change for the area studied.

An analysis of the results from the above surveys showed that the derived assessment of changes was usually affected by poor consistency since the surveys carried out at different times over the same area were often inconsistent in classification, quality of remote sensing data, interpretation techniques, etc., and involved significant subjectivity in class delineation. These factors led to an unknown number of pseudo-changes. Though the inconsistencies between results on the two dates under consideration tended to auto-compensate over large survey areas, such as a whole country, they failed to provide a reliable and location-specific estimate of changes. The gathering of consistent information on the process of change from such studies was not possible at all.

In view of the foregoing situation the Project decided to develop a more reliable and consistent system of global tropical forest cover monitoring based on the concept of continuous forest inventory, well documented in the forestry literature as an efficient technique for providing reliable forest state and change information. Moreover, it was clear that consistency, or coherence, between historical and recent observations was of paramount importance in any survey of change.

Remote sensing features

Related to the interpretation of satellite data was the question concerning the classification system for observing and describing changes over a given time period. A simple *forest-non forest* dichotomy, for instance, could not provide all the information needed to describe forest degradation, e.g., change of density, forest fragmentation, changes into long and short fallow, etc. which are important processes affecting forest biomass and biodiversity. While setting higher goals regarding the types of change to be detected, the limitations associated with high-resolution satellite data were kept in view. The classification system adopted was a compromise between two conflicting considerations (R. Baltaxe, R. Drigo, 1991).

A point interpretation of change over time was a necessary condition for producing consistent "change matrices" which had been accepted as one of the essential objectives of the global survey. How could one ensure the spatial and, most important, thematic consistency required to produce reliable change matrices? How could it be done in a simple, unsophisticated way that would facilitate transfer to and implementation in developing country conditions without compromising the quality of results?

In answer to these questions a new procedure was developed which was termed **interdependent interpretation procedure** (R. Drigo 1991). This procedure consists of visual interpretation of both images (historical and recent) by the same interpreter (from the region and familiar with the location) and at the same time based on a single interpretation process. This procedure allows for **spatial and thematic co-registration of the two interpretations**, regardless of any geometric and radiometric distortions of the satellite images used.

The consistency of the classification of satellite data acquired on two separate dates, resulting from this procedure, makes it probably the single most important element of the whole survey.

In order to allow for the immediate processing and verification of results at sampling unit level, a user-friendly data recording/processing system was developed based on customized LOTUS 1-2-3® spreadsheet software and dot grid of appropriate size. The simplicity and low sophistication of the system ensured the smooth implementation of the procedure in all conditions, the only requirements being one personal computer of minimum capacity and a power supply.

The interdependent interpretation procedure, classification system and compilation procedure were discussed and disseminated through (i) four regional workshops (held, chronologically, in Thailand, Mexico, Kenya and Cameroon) with the participation of 31 tropical countries; and (ii) ten training sessions at the level of national institutions.

The interpretation technique was implemented at selected regional and national forestry and/or remote sensing institutions which have a good knowledge of the sample locations and have been traditionally involved in forest resources assessment activities. This decentralized approach was chosen with the twofold objective of **strengthening national capacities for forest monitoring** and **improving the quality of image interpretation**.

Chapter II

Methodology

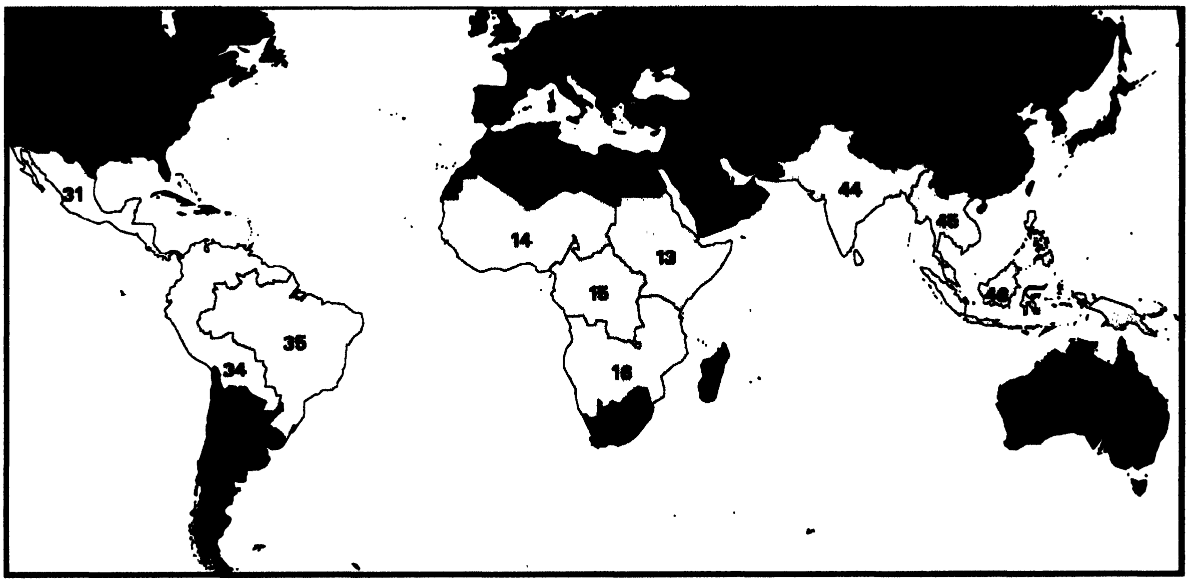
2.1 STATISTICAL DESIGN

2.1.1 Sampling design

The sampling frame

The survey covered the entire tropical zone. The tropical area was divided into three regions and ten sub-regions, each containing a group of countries on the basis of their geographical proximity, as shown in Figure (2.1.1) 1 below:

Figure (2.1.1) 1 : Sub-regions under assessment



Africa	Latin America	Asia
13 East Sahelian Africa	**31** Central America and Mexico	**44** South Asia
14 West and West Sahelian Africa	**34** Tropical South America	**45** Continental South East Asia
15 Central Africa	**35** Brazil	**46** Insular South East Asia
16 Southern Africa		

The continuous recording of the earth's surface by Landsat satellites is divided into scenes (approximately) 185 x 185 km in size. This is reflected in the World Reference System 2 (WRS 2, in use since Landsat mission four, July 1982) whose paths and rows show the nominal ground position of each scene. Landsat scenes cover the whole of the tropics and a Sampling Unit (SU) was defined as the entire area of a scene (approximately 3.2 million hectares). The WRS 2 therefore provided a convenient depiction of the distribution of Sampling Units over the tropics and a ready-made sampling frame for the remote sensing survey.

For assessment of the state of forest cover a SU was defined as the entire 1990 image. For assessment of change in forest cover a SU was defined as the overlap area of a pair of multi-date Landsat scenes (e.g., from 1980 and 1990). This in effect means that the sampling units are not equal in size.

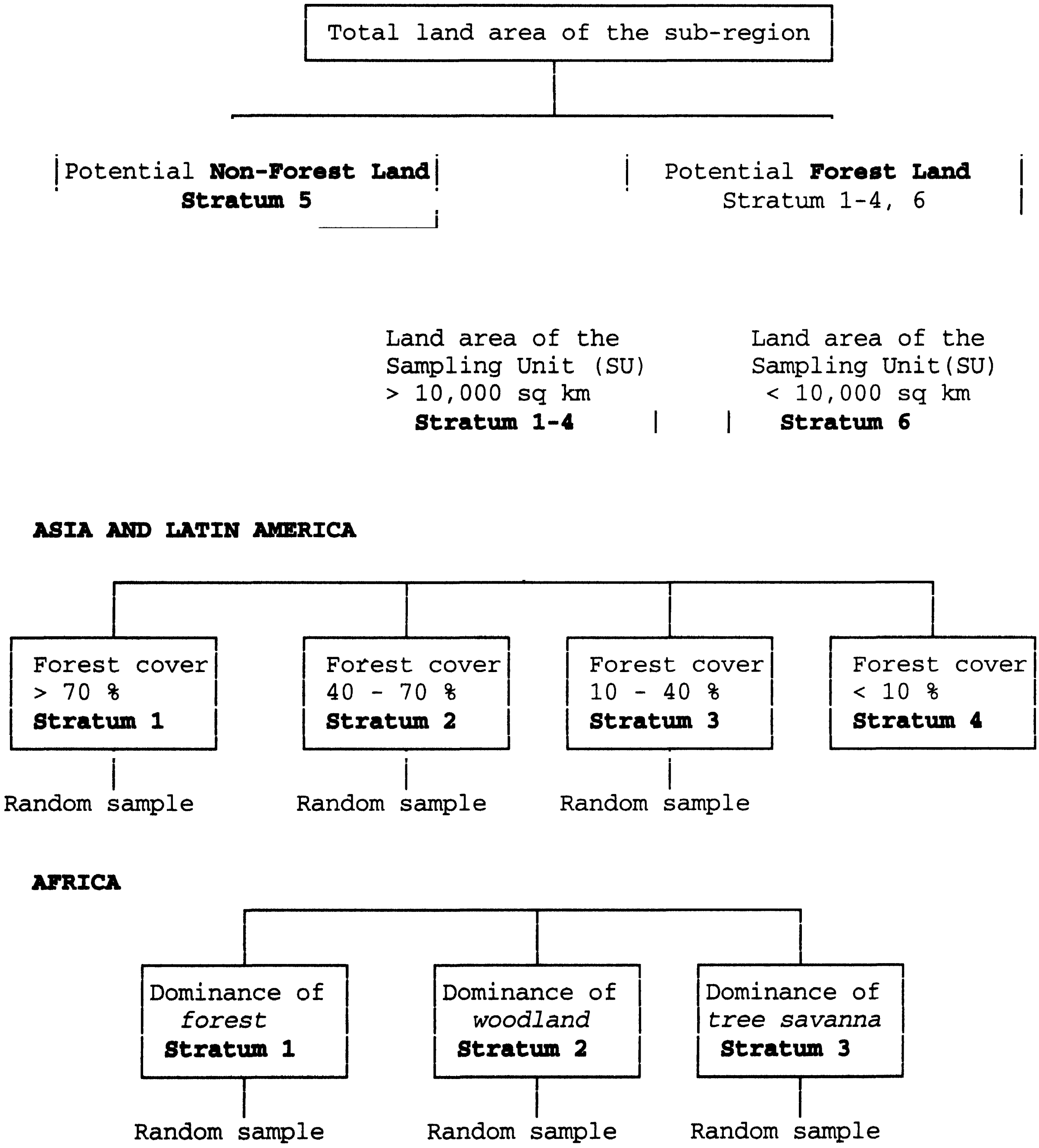
The sampling design

As the project had a number of statistical and cartographic databases deriving from global tropical data, possibilities were open to reduce the standard error of the survey by using this available information.

Keeping this in view, a two-stage stratified random sampling method was chosen. The first stage of stratification was based on geographical contiguity by dividing the survey area into sub-regions. The second stage of stratification was based on forest cover and forest dominance. The required information for these purposes was obtained by overlaying the following cartographic database, viz.: (i) the sampling frame; (ii) vegetation data; and (iii) eco-floristic zone map.

An overview of the stratification process is given in Figure (2.1.1) 2.

Figure (2.1.1) 2: Sample design flowchart for a specific sub-region



Of the six strata thus defined, only the first three were sampled: stratum 5 (potential non-forest land) was outside the scope of the present survey; stratum 6 (land area of the SU less than one million ha) and stratum 4 (forest cover of less than 10 percent) were also excluded owing to cost/benefit considerations.

Land area of at least one million hectares per scene was taken as the minimum required for multi-date analysis. According to the project vegetation map, strata 1, 2 and 3 comprise 94 percent of total tropical forest area. Thus, the forest area not covered was relatively small.

Table (2.1.1) 1 shows the distribution of Landsat frames by stratum and sub-region while the land area within Landsat frames is reported in Annex 4.

Table (2.1.1) 1: Distribution of Landsat frames by stratum and sub-region

	1 Forest	2 Woodland	3 Tree savanna	Total surveyed	4 & 5 Non-forest or forest<10%	6 Land area <1m ha	Total not surveyed	Grand Total
East Sahelian Africa	34	0	51	85	113	17	130	**215**
West Sahelian and West Africa	26	19	50	95	187	41	228	**323**
Central Africa	107	19	21	147	6	3	9	**156**
Tropical Southern Africa	0	94	40	134	85	31	116	**250**
Sub-total Africa [1]	**167**	**132**	**162**	**461**	**391**	**92**	**483**	**944**

	1 Forest cover >70%	2 Forest cover 40-70%	3 Forest cover 10-40%	Total surveyed	4 & 5 Non-forest or forest<10%	6 Land area <1m ha	Total not surveyed	Grand Total
Mexico and Central America	14	33	23	70	37	55	92	**162**
Tropical South America	83	40	39	162	56	32	88	**250**
Brazil	146	36	51	233	84	24	108	**341**
Sub-total Latin America [2]	**243**	**109**	**113**	**465**	**177**	**111**	**288**	**753**
South Asia	0	23	65	88	99	50	149	**237**
Continental South East Asia	0	39	42	81	1	41	42	**123**
Insular South East Asia	54	24	30	108	5	206	211	**319**
Sub-total Asia	**54**	**86**	**137**	**277**	**105**	**297**	**402**	**679**
GRAND TOTAL	**464**	**327**	**412**	**1203**	**673**	**500**	**1173**	**2376**

[1] Insular Africa excluded

[2] Caribbean Islands excluded

Sampling intensity

For the present survey round a sample size of 117 sampling units was fixed. This sample size was determined in view of practical constraints, including current levels of funding.

Table (2.1.1) 2 provides the expected standard errors by region (at 95 percent probability) for forest area, calculated during the design phase of the survey.

Table (2.1.1) 2: Allocation of sampling units by region and expected sampling error

	sampling units		**Estimated sampling**
Region	**Total no.**	**Sample size**	**error (percent)**
Africa	461	47	8.0
Latin America	465	40	4.7
Asia	277	30	8.2
TOTAL	**1203**	**117**	**3.9**

The distribution of sampling units (SUs) according to sub-regions and strata within them are given in Table (2.1.1) 3. In the first stage the SUs were distributed to sub-regions proportionally to the expected deforestation area therein calculated during the Phase I of the project (FORIS statistics).

The allocation of SUs in the second stage was proportional to the total land area of the stratum, i.e., by using the same sampling fraction for each stratum. The only exception was for Latin America where the number of SUs was constant in each stratum. This was done to reduce the sampling fraction in stratum 1 (forest cover above 70 percent) which includes many units but minimal rates of change.

For statistical reasons it was decided to allocate a minimum of two units per stratum and also to merge with the closest stratum those strata where the number of SUs was less than 10. Therefore, the number of strata per sub-region can vary. The resulting sampling plan by region, sub-region and stratum is shown in Table (2.1.1) 3.

To permit the accurate estimation of forest area and its change per sub-region (say, with a standard error of less than 5 percent) an expansion of the sampling would be required. This could be achieved in a later sampling round of the tropical forest resources assessment. By continuing the survey and thereby accumulating an increasing number of SUs, statistically sound results of known precision can be provided for the regions and sub-regions surveyed.

Table (2.1.1) 3: Allocation of sampling units among sub-regions and strata

Region/Sub-region	**Stratum**			
	1	**2**	**3**	**Total**
East Sahelian Africa	4	-	6	10
West Sahelian and West Africa	3	2	5	10
Central Africa	8	2	2	12
Tropical Southern Africa	-	11	4	15
Sub-total Africa	**15**	**15**	**17**	**47**
Mexico and Central America	3	4	3	10
Tropical South America	5	4	4	13
Brazil	6	5	6	17
Sub-total Latin America	**14**	**13**	**13**	**40**
South Asia	-	2	8	10
Continental South East Asia	-	5	5	10
Insular South East Asia	5	2	3	10
Sub-total Asia	**5**	**9**	**16**	**30**
GRAND TOTAL	**34**	**37**	**46**	**117**

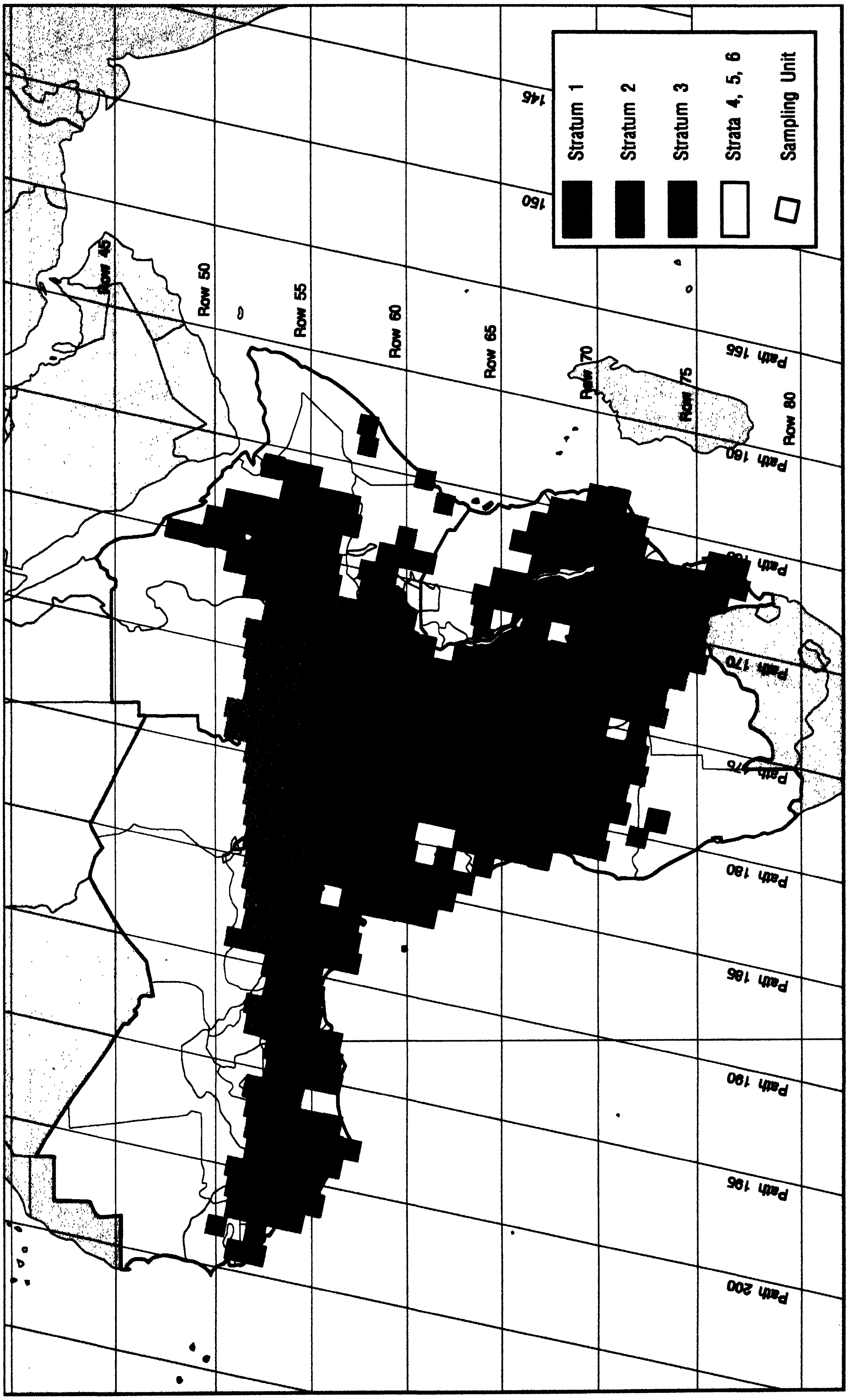


Figure (2.1.1) 3a: Africa Region - Sampling Frame and selected Sampling Units

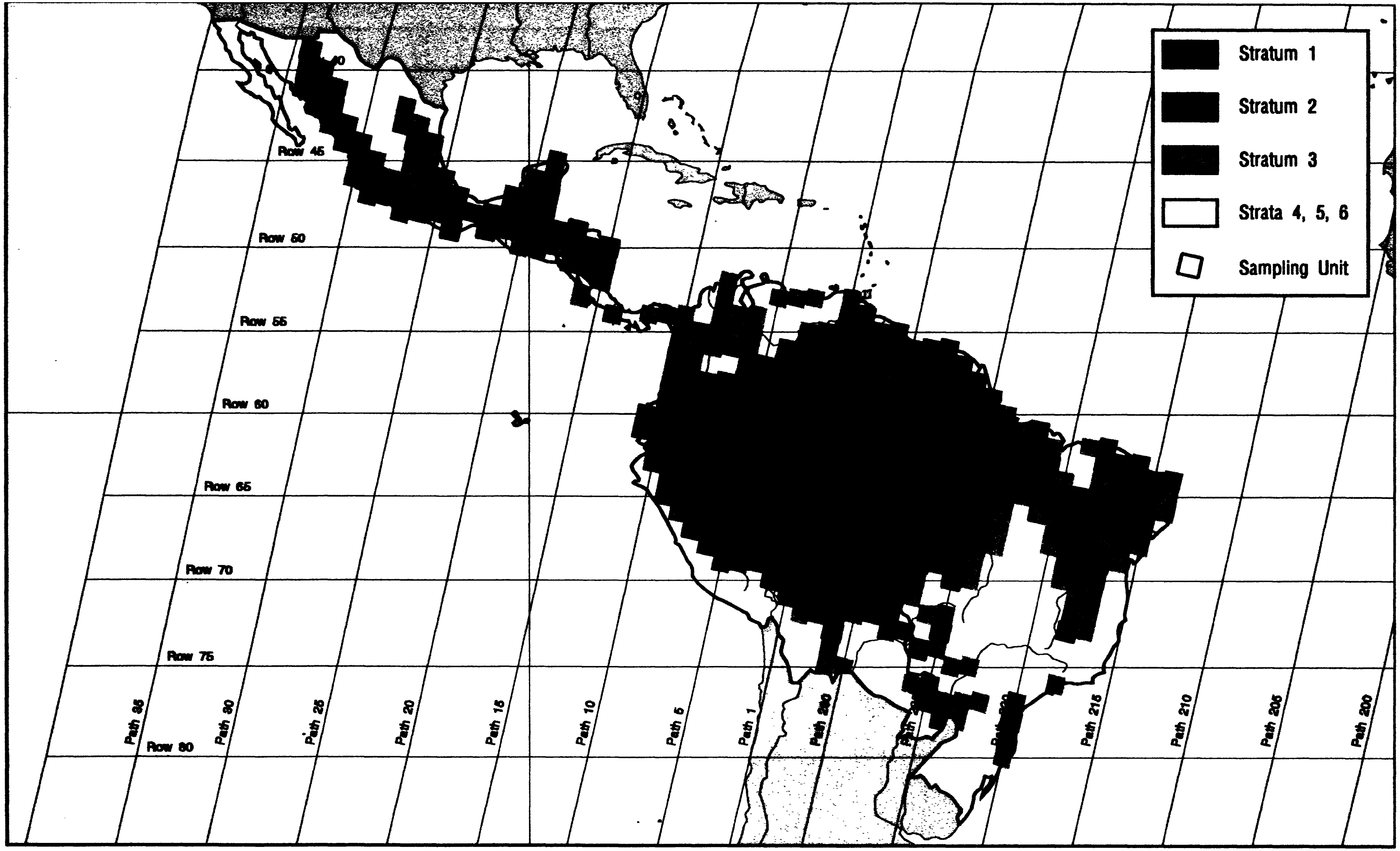


Figure (2.1.1) 3c: Latin America Region - Sampling Frame and selected Sampling Units

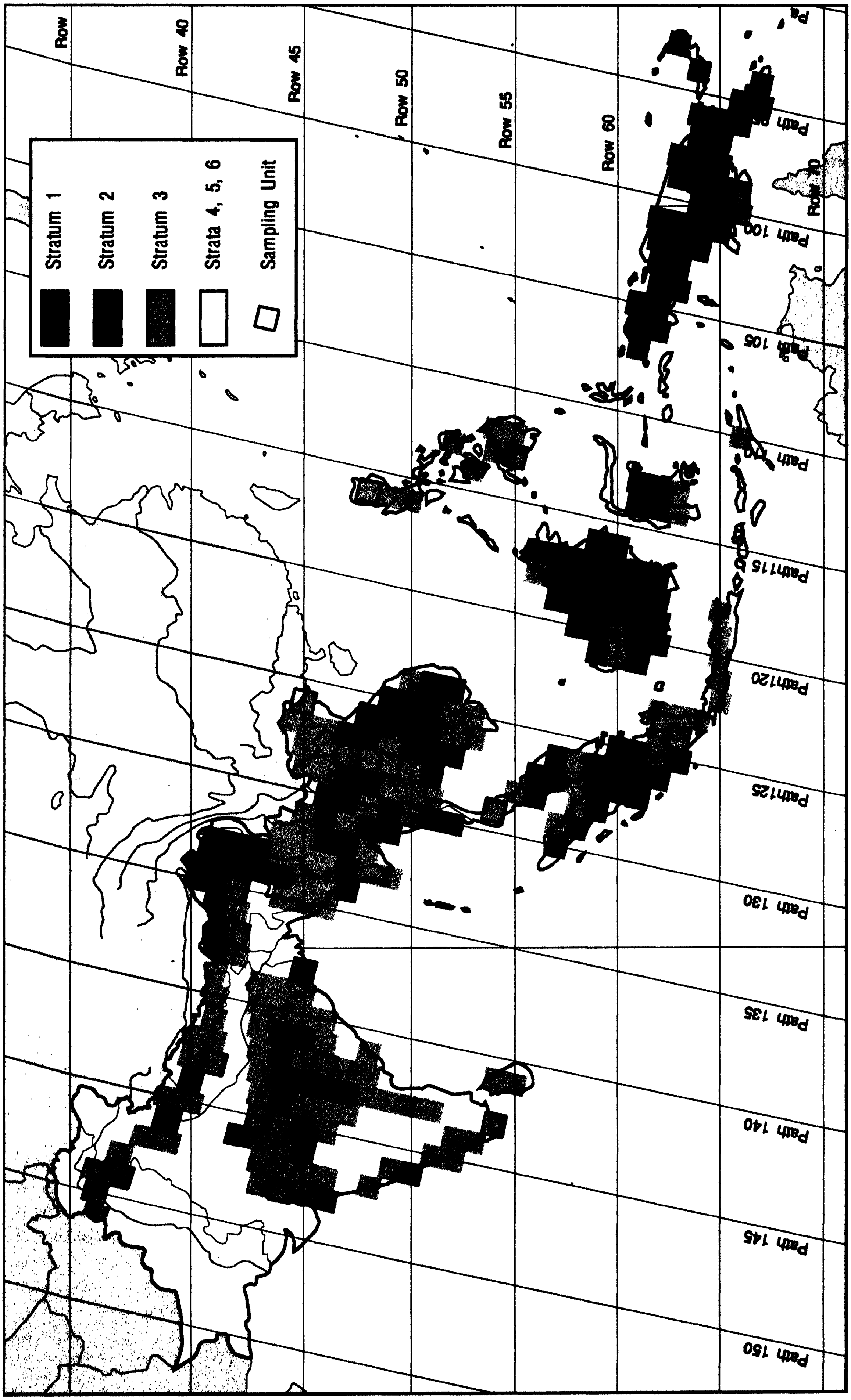


Figure (2.1.1) 3c: Asia Region - Sampling Frame and selected Sampling Units

2.1.2 Analytical model

Preparatory treatment of data collected

The data collected from interpretation of the pair of satellite images at a sample location were processed and a database was created with the results on state and change of forest cover, the latter in the form of change matrices.

The first statistical operation is standardization of observed change matrices involving the transformation of values from the period observed (i.e., dates of acquisition of the satellite images used) to the standard period 1980 - 1990. A statistical procedure and appropriate software have been developed to carry out this data transformation on a routine basis, as described in Section 2.5.

Estimation of forest cover and annual deforestation rate

The estimates of forest cover in 1990, forest cover in 1980 and of annual deforestation rates have been calculated at five different levels:

1) sampling unit level;
2) stratum level;
3) sub-regional level;
4) regional level; and
5) global level.

For the estimates at levels 2 through 5, the margin of standard error has also been calculated.

As mentioned earlier, for each sampling unit there are two Landsat images, measured on two different occasions. At the sampling unit level two estimates have been made. The first one was an estimate of forest cover and the second was an estimate of the deforestation rate. The forest cover estimates, per sampling unit, have been based only on the latest Landsat image of the pair. The total Landsat scene area, denoted by a capital letter, has been used in the estimation process. To estimate deforestation, the common area of the two Landsat images has been used (denoted by small letters).

The following notations have been used in the formulae:

i	denotes the sampling unit	N_{lkh} =	number of units in stratum h
h	denotes the stratum	n_{lkh} =	number of sampling units in stratum h
k	denotes the sub-region	np_{lkh}=	number of available sampling units in stratum h
l	denotes the region	m_l =	number of sub-regions in region l
		p =	number of regions

t_{lkhi1}, t_{lkhi2} = acquisition times of the satellite images of a sampling unit
$d_{lkhi} = t_{lkhi2} - t_{lkhi1}$ = time difference between the two satellite images in the pair of images
$T_{lkhi} = 90 - t_{lkhi2}$ = time difference between 1990 and the latest satellite image
LA_{lkhi} = land area interpreted for the latest image
r = annual compound rate of change
$Fc(90)$ = relative forest cover in 1990
$Fc(80)$ = relative forest cover in 1980
FA_{lkhi} = forest area in ha for the latest image
fa_{lkhi1}, fa_{lkhi2} = forest area in ha for common area at t_{hi1} and t_{hi2} times
L_{lkh} = land area in stratum h

A circumflex accent (^) over a variable denotes an estimate of that variable.

Only examples of estimation formulae are given at the sampling unit and the global levels. A complete description of formulae used at all levels is given in the Project paper "Estimates of Tropical Forest Cover, Deforestation and Matrices of Change" by E. Rovainen [PhD thesis, Swedish University of Agricultural Sciences (SUAS), 1994].

Estimates at sampling unit level

1990 forest cover: $F(90)_{lkhi} = \frac{FA_{lkhi}}{LA_{lkhi}} * (1 + r_{lkhi80 \Rightarrow 90})^{T_{lkhi}}$

1980 forest cover: $F(80)_{lkhi} = \frac{FA_{lkhi}}{LA_{lkhi}} * (1 + r_{lkhi90 \Rightarrow 80})^{t_{lkhi2} - 80}$

where: $r_{lkhi80 \Rightarrow 90} = \left(\frac{Fc90}{Fc80} \right)^{1/t} - 1$ and $r_{lkhi90 \Rightarrow 80} = \left(\frac{Fc80}{Fc90} \right)^{1/t} - 1$

Estimates at global level

1990 forest cover:

$$\hat{F}(90) = \frac{\sum_{l=1}^{p} L_l \cdot \hat{F}(90)_l}{\sum_{l=1}^{p} L_l} = \frac{\sum_{l=1}^{p} \sum_{k=1}^{m_l} \sum_{h=1}^{3} L_{lkh} \cdot \hat{F}(90)_{lkh}}{\sum_{l=1}^{p} \sum_{k=1}^{m_l} \sum_{h=1}^{3} L_{lkh}}$$

, and

Standard error of forest cover estimate:

$$se(\hat{F}(90)) = \sqrt{\frac{\sum_{l=1}^{p} \sum_{k=1}^{m_l} \sum_{h=1}^{3} \left[L_{lkh} \cdot se\left(\hat{F}(90)_{lkh} \right) \right]^2}{\left(\sum_{l=1}^{p} \sum_{k=1}^{m_l} \sum_{h=1}^{3} L_{lkh} \right)^2}}$$

Annual deforestation rate:

$$\hat{R} = 1 - 10 \cdot \hat{r} = \frac{\sum_{l=1}^{p} \sum_{k=1}^{m_l} \sum_{h=1}^{3} L_{lkh} \cdot \hat{F}(90)_{lkh}}{\sum_{l=1}^{p} \sum_{k=1}^{m_l} \sum_{h=1}^{3} L_{lkh} \cdot \hat{F}(80)_{lkh}} = \frac{\sum_{l=1}^{p} \sum_{k=1}^{m_l} \sum_{h=1}^{3} L_{lkh} \cdot \left(\frac{\sum_{i=1}^{n_{lkh}} LA_{lkhi} \cdot \hat{F}(90)_{lkhi}}{\sum_{i=1}^{n_{lkh}} LA_{lkhi}} \right)}{\sum_{l=1}^{p} \sum_{k=1}^{m_l} \sum_{h=1}^{3} L_{lkh} \cdot \left(\frac{\sum_{i=1}^{n_{lkh}} LA_{lkhi} \cdot \hat{F}(80)_{lkhi}}{\sum_{i=1}^{n_{lkh}} LA_{lkhi}} \right)}$$

Standard error of deforestation rate estimate:

$$se(\hat{R}) = \sqrt{\frac{\sum_{l=1}^{p} \sum_{k=1}^{m_l} \sum_{h=1}^{3} w_{lkh}^2 \cdot n_{lkh} \cdot \left[s(y)_{lkh}^2 + \hat{R}^2 \cdot s(x)_{lkh} - 2 \cdot \hat{R} \cdot c(y,x)_{lkh} \right]}{\left(\sum_{l=1}^{p} \sum_{k=1}^{m_l} \sum_{h=1}^{3} w_{lkh} \sum_{i=1}^{n_{lkh}} x_{lkhi} \right)^2}}$$

Where the following notation was used:

$$y_{lkhi} = LA_{lkhi} \cdot \hat{F}(90)_{lkhi}$$

$$x_{lkhi} = LA_{lkhi} \cdot \hat{F}(80)_{lkhi}$$

$$s(y)^{2}_{lkh} = \frac{\sum^{n_{lkh}} (y_{lkhi} - \bar{y}_{lkh})}{n_{lkh} - 1}$$

$$c(y,x)_{lkh} = \frac{\sum_{i=1}^{n_{lkh}} (y_{lkhi} - \bar{y}_{lkh}) \cdot (x_{lkhi} - \bar{x}_{lkh})}{n_{lkh} - 1}$$

and letting

$$w_{lkh} = \frac{L_{lkh}}{\sum_{i=1}^{n_{lkh}} LA_{lkhi}}$$

2.2 CLASSIFICATION

The classification system adopted in the present survey has been designed to meet the following requirements:

- To allow a meaningful description of changes, with special attention to forest cover, and permitting the description and measurement of changes within the forest (degradation, amelioration) as well as changes from forest to non-forest and vice-versa (deforestation, afforestation).
- To be simple, based on clear definitions and applicable to all tropical conditions.
- To include those classes usually detectable on high resolution satellite data with an acceptable degree of accuracy.
- To correspond, to the largest possible extent, to the standard definitions used in FAO's periodic assessment of forest resources.

The classification scheme subsequently developed is presented in Table (2.2) 1, on the following page, and described in detail in Annex 5. The land cover classification has three main characteristics:

- a hierarchical structure to permit the unambiguous aggregation of the classes at each level to the next level or levels;
- a simple dichotomy at each level, based on criteria usually detectable on high resolution satellite data (HRSD), or readily inferred, to facilitate the interpreter's decision at that level and about whether it would be possible to proceed to the next lower (more detailed) level (see the interpretation key in Annex 5;
- the inclusion of all classes of interest to the assessment of the state and change of forest cover in a form obtainable from HRSD.

Land cover classification: List of main and additional classes

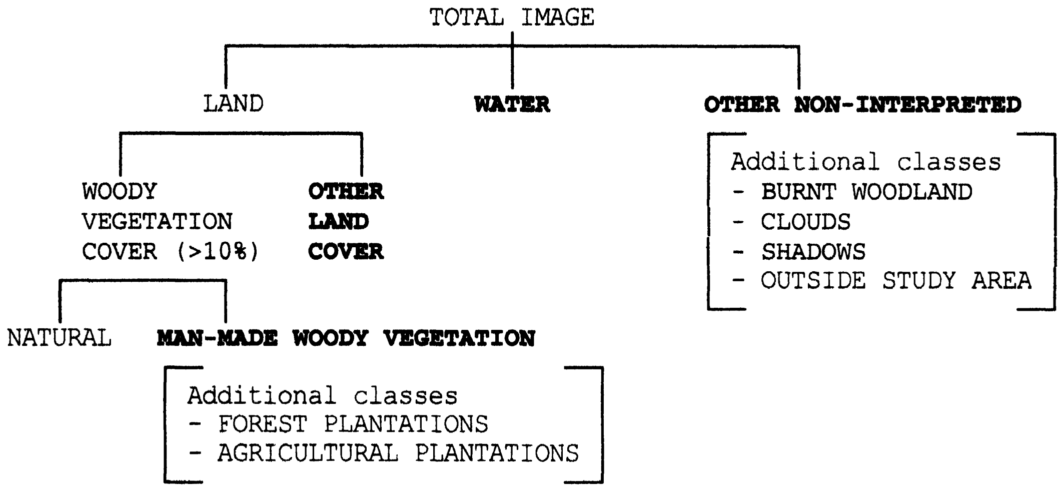
Main Classes		Additional Classes	
Closed Forest	(canopy cover >40%)	**High density**	(canopy cover >70%)
		Medium density	(canopy cover 40-70%)
Open Forest	(canopy cover 10-40%)		
Long Fallow	(forest affected by long fallow shifting cultivation)		
Fragmented Forest	(mosaic of forest / non-forest)	**Dense fragmented**	(forest fraction 40-70%)
		Sparse fragmented	(forest fraction 10-40%)
Shrubs		**Dense shrubs**	(canopy cover >40%)
		Sparse shrubs	(canopy cover 10-40%)
Short Fallow	(agricultural areas with short fallow period)		
Other Land Cover			
Water			
Plantation	(man-made woody vegetation)	**Forest plantation**	
		Agricultural plantation	

Classification levels

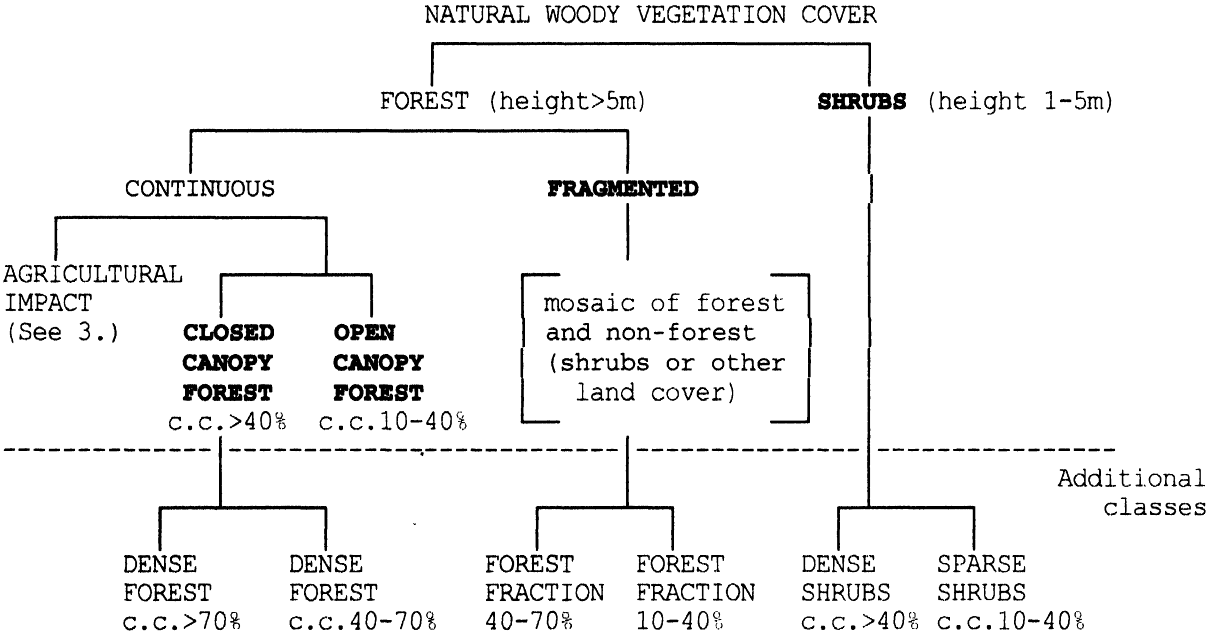
In order to allow a certain flexibility in carrying out the classification exercise, but to ensure at the same time a common minimum baseline, the classification comprises two levels, viz, **main classes** and **additional classes**. The main classes (10 in total) identify the minimum common standard for sub-regional, regional and global reporting of results and for all change matrices. The additional classes, related hierarchically to the main classes, have been used, whenever appropriate, in the interpretation of the recent satellite images.

Table (2.2) 1: Classification Scheme

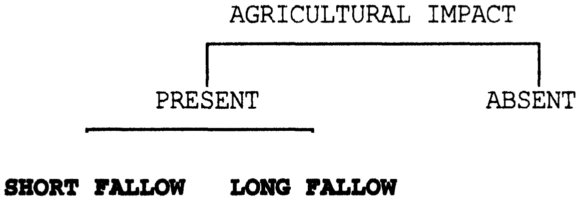
1. Preliminary Image Interpretation Classes



2. Classification of Natural Woody Vegetation Cover



3. Agricultural Impact on Continuous Natural Forest



The classes with **BOLD** characters belong to the **main** classification level.
c.c. = canopy cover

One distinctive feature of the classification scheme lies in its **long fallow** and **short fallow** classes, both of which identify areas of natural woody vegetation affected by shifting cultivation. The distinction between *long* and *short* has been made with the purpose of dividing the total area under shifting cultivation into "predominantly forested", no matter how much degradation has occurred, and "predominantly non-forested" on the basis of the estimated intensity of cultivation or, more specifically, of the rotation cycle. This distinction brings some clarity to the controversial category of "shifting cultivation" which, without further subdivision, is sometimes considered *non-forest* (i.e., classified as "other wooded land" according to FAO-FORIS definition) and sometimes *forest* (i.e., according to the definition used by the Forest Survey of India).

Another distinctive element lies in the inclusion of the (additional) class **burnt woodland** under the (main) class **other non interpreted**, together with **clouds** and **shadows**. This class has been introduced with the purpose of preventing errors in the estimation of changes in woodland areas as consequence of recurrent fires. In fact the areas under woodland, viz, the Myombo Woodlands in Africa, Dry Dypterocarps Forests in Asia and Cerrado formations in Latin America, are frequently crossed by fires that destroy only (or mainly) the grass layer present under the tree cover, leaving the latter unaffected. However, recent burnings , shown on the images as black patches, prevent the assessment and interpretation of woody vegetation cover by hiding the spectral signature of the usually sparse tree canopy.

The class **burnt woodland**, as well as all additional classes under the main class **other non interpreted**, have been excluded from the analysis of change. Class transitions are considered valid only when both the class of origin and the class of destination are visible and can be interpreted clearly (not by deduction).

2.2.1 Definition of forest and forest area changes

The land cover classes presented in the preceding section have been used to estimate the pan-tropical forest cover and its changes during a ten-year period. However, since there is no single class that unequivocally represents "the" forest, it is essential to specify clearly which class groupings, or **definitions of forest** have been adopted and how such definitions affect the classification and estimation of forest changes, viz, deforestation, degradation, afforestation, etc.

The land cover classification includes nine classes (main level classification, excluding the class **other non interpreted**) which have been defined to represent in relative detail the full range of land cover conditions relevant to the analysis of change in woody vegetation.

The first four classes represent the forest under various conditions: grades of density (**closed** and **open**), spatial disturbance (**fragmented**[1]) and temporal disturbance (**long fallow** shifting cultivation).

These classes can be grouped to reach various definitions of forest, from the most strict one that includes only the class **closed forest** to the broadest one which includes all four classes. It is implicit, but not generally recognised, that the definition of ***forest*** determines the definition of ***deforestation***.

A narrow concept of forest, composed of one class only, implies a wide concept of deforestation since any transition from that single class would represent deforestation.

A broad concept of forest, composed of several classes, implies a narrow concept of deforestation since only transitions *outside* that group of classes would be considered deforestation while the transitions *within* the group would be defined as degradation, fragmentation, amelioration, etc.

One important factor to be considered is that for a deeper analysis of forest area changes a broader definition of forest is preferable since it allows for finer differentiation among changes and a better description of their environmental impact.

However, since there is no single definition of forest that satisfies everyone and all purposes and in order to highlight the relativity of the concept of forest, three class groupings have been used in the present survey and three distinct *forest cover* and *deforestation rates* have been estimated.

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[1] The area covered by actual forest in the class ***fragmented forest*** is estimated, on average, at one-third of the class area (one-third forested and two-thirds non forested); therefore, when estimating the forest cover only 33 percent of the total fragmented forest class area has been considered.

The forest definitions applied were:

F1 = closed forest
F2 = closed + open forest + 2/3 fragmented forest
F3 = closed + open forest + fragmented forest + long fallow

F1 represents forest in the strictest sense, mostly dense, not fragmented nor (heavily) degraded.

F2 is a definition aimed at matching the concept of forest used in FORIS (Forest Resources Information System) by FAO in its periodic assessments based on existing information. According to the FORIS definition the class long fallow is excluded; the reduction factor applied to fragmented forest is due to two factors: (i) forest blocks smaller than 100 hectares are not included, according to FORIS definition, but, in practice, (ii) composite forest/non-forest classes have been considered when more detailed classes were not available, and a certain forest fraction has been estimated and included in FORIS statistics, which is fairly common.

F3 represents forest in its broadest sense, including all types and phases of degradation (but still with the connotation of forest). **This definition of forest, that allows for the most detailed differentiation among changes, has been used in the analysis of change processes presented below, unless otherwise specified.**

It is important to note here that classifications are always arbitrary and their validity lies only within their assumptions and definitions. Thresholds do not exist in nature and classes are but temporary features. In this context, the system of definitions adopted in this study represents an attempt to "pin down" certain terms and concepts that are commonly used (and frequently misused), but rarely defined, and this can often be a source of misinterpretation.

Definition of changes

As mentioned earlier the conceptual grouping of land cover classes into categories (such as forest and non-forest) has strong implications for the classification of class transitions.

In order to reduce the 81 (9 x 9) possible changes to a meaningful number of change categories, and based on the F3 definition of forest, the classes have been grouped hierarchically into five Land Cover Categories, as shown in Table (2.2.1) 1 below:

Table (2.2.1) 1: Grouping of land cover classes into **land cover categories**

	Land Cover Categories	*Land Cover Classes*
NATURAL FOREST	**Continuous Forest**	Closed Forest Open Forest Long Fallow
	Fragmented Forest	Fragmented Forest
NON-FOREST	**Other Wooded Land**	Shrubs Short Fallow
	Non-Wooded Areas	Other Land Cover Water
MAN-MADE WOODY VEGETATION		Plantations (forest and agricultural)

Table (2.2.1) 2 below shows the categories of change resulting from transition among the land cover categories defined above.

Table (2.2.1) 2 : Key to change matrix analysis. Change categories relative to the F3 definition of forest

Interpretation classes at date 1 (1980)			*Interpretation classes at date 2 (1990)*								
COVER CATEGORIES			**Natural Forest**				**Non-Forest**				**Man-made Woody Veg.**
			Continuous Forest			**Frag-mented forest**	**Other Wooded**		**Non-Wooded**		
		Cover Classes	**closed forest**	**open forest**	**long fallow**		**short fallow**	**shrubs**	**other land cover**	**water**	**plantations**[1]
Natural Forest	**Continuous Natural Forest**	**closed forest**	-	Deg	Deg	2/3Def	Def	Def	Def	Def	Re/Cap
		open forest	Am	-	Deg	2/3Def	Def	Def	Def	Def	Re/Ib
		long fallow	Am	Am	-	2/3Def	Def	Def	Def	Def	Re/Ib
	Fragmented forest		2/3Af	2/3Af	2/3Af	-	1/3Def	1/3Def	1/3Def	1/3Def	2/3Af/Ib
Non-Forest	**Other Wooded**	**short fallow**	Af	Af	Af	1/3Af	-	Db	Db	Db	Af/Ib
		shrubs	Af	Af	Af	1/3Af	Ib	-	Db	Db	Af/Ib
	Non-Wooded	**other land cover**	Af	Af	Af	1/3Af	Ib	Ib	-	-	Af/Ib
		water	Af	Af	Af	1/3Af	Ib	Ib	-	-	Af/Ib
Man-made Woody V.		**plantations**[1]	-	Deg	Deg	2/3Def/Db	Def/Db	Def/Db	Def/Db	Def/Db	-

Change categories:

Def = **Deforestation** of Continuous Natural Forest (from forest classes to non-forest classes)

2/3Def = **Fragmentation** of Continuous Natural Forest (partial deforestation, or loss of 2/3 of the actual forest)

1/3Def = **Deforestation** of Fragmented Forest (the actual forest loss of is estimated at 1/3 of the total area)

Deg = **Degradation** (decrease of density or increase of disturbance in forest classes)

Db = **Decrease** of non-forest woody **biomass**

Ib = **Increase** of non-forest woody **biomass**

Am = **Amelioration** (increase of density or decrease of disturbance in forest classes)

Af = **Afforestation** (from non-forest classes to forest classes or forest plantation)

1/3Af = **Partial afforestation** (from non-forest to fragmented forest)

2/3Af = **Partial afforestation** (from fragmented forest to Continuous Natural Forest)

Re = **Reforestation** (from forest classes to forest plantation)

Cap = **Conversion** (from closed forest to agricultural plantation)

However, in order to answer with adequate coherence and conciseness to specific questions such as: *what is the rate of deforestation and forest degradation?* it was necessary to collapse the complex cluster of definitions given in Table (2.2.1) 2 into few simple ones.

Calculation of change rates

With the purpose of producing few meaningful statistics, the following definitions have been used: **gross deforestation**, **net deforestation**, and **net forest degradation**, for which areas and rates of change have been calculated and presented under Chapter IV, "Results and findings". In these definitions the natural forest has been considered as the main focus, under the consideration that there would be a high interest in knowing what has happened to the 1980 natural forest, in consideration of its important role from the environmental view point, separately from the establishment, natural or man-made, of "new" forest.

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[1] The class **plantations** includes both agricultural and forestry plantations for which different change categories apply. In view of this consideration, statistics related to transitions involving the class plantations have been accounted for as a separate category.

The definitions used, shown graphically in Table (2.2.1) 3, are the following:

- **Gross Deforestation** has been calculated as the sum of all area transitions from natural forest classes (continuous and fragmented) to all other classes.
- **Net Deforestation** has been calculated as the area of Gross Deforestation minus all area transitions into natural forest classes from all other classes.
  In all cases concerning partial deforestation or afforestation, involving the class fragmented forest, the area considered was that of the estimated forest or non-forest fraction.
- **Net Degradation of Natural Forest** has been calculated from the area transitions among natural forest classes, by adding all changes corresponding to *degradation* minus those corresponding to *amelioration.*

Table (2.2.1) 3 : Definitions of gross and net deforestation and forest degradation

Interpretation classes at date 1 (1980)			*Interpretation classes at date 2 (1990)*								
COVER CATEGORIES			**Natural Forest**				**Non-Forest**				**Man-made Woody Veg.**
			Continuous Forest			**Frag-mented forest**	**Other Wooded**		**Non-Wooded**		
		Cover Classes	**closed forest**	**open forest**	**long fallow**		**short fallow**	**shrubs**	**other land cover**	**water**	**planta-tions**
Natural Forest	**Continuous Natural Forest**	**closed forest**	-	■	[3]	■	■	■	■	■	■
		open forest	▨	-	■	■	■	■	[1]	■	■
		long fallow	[4]	▨	-	■	■	■	■	■	■
	Fragmented forest		2/3Af	2/3Af	2/3Af	-	■	■	■	■	■
Non-Forest	**Other Wooded**	**short fallow**	Af	Af	Af	1/3Af	-	Db	Db	Db	Af/Ib
		shrubs	Af	Af	Af	1/3Af	Ib	-	Db	Db	Af/Ib
	Non-Wooded	**other land cover**	Af	[2] Af	Af	1/3Af	Ib	Ib	-	-	Af/Ib
		water	Af	Af	Af	1/3Af	Ib	Ib	-	-	Af/Ib
Man-made Woody V.		**plantations**	-	Deg	Deg	2/3Def/Db	Def/Db	Def/Db	Def/Db	Def/Db	-

Gross deforestation = ■ [1]

Net deforestation = ■ [1] **minus** □ [2]

Net forest degradation = ■ [3] **minus** ▨ [4]

In order to complete the analysis of state and change of the entire tree cover, natural and man-made, the **balance** between **natural forest** and **man-made woody vegetation** has been calculated and presented separately; the balance has been calculated as the algebraic sum of the areas, and changes, of natural forest and of man-made woody vegetation at 1980 and 1990.

In these calculations transitions between natural forest classes and the class man-made woody vegetation have been considered twice: as deforestation (or afforestation), when referred to the natural forest and as increase (or decrease) of planted area, when referred to the man-made woody vegetation; being necessarily of opposite sign, these double counting is reconciled in the calculation of the overall balance.

2.3 INTERDEPENDENT INTERPRETATION PROCEDURE

The most difficult and crucial aspect in the estimation of change lies in the distinction between the variations pertaining to the object under study and those pertaining to the approach and instruments used or, in other words, between real changes and spurious changes. This problem acquires particular relevance where the changes to be detected are small and/or indistinct. With annual deforestation rates ranging between 0.5 and 1 percent, the changes in forest cover are relatively small and often poorly distinguishable even over a ten-year span.

When the objective of a survey is to achieve a detailed analysis of class-to-class transitions, it is essential that transition estimation be based on an approach that ensures the highest level of consistency, or coherence, between historical and recent observations, in order to reduce spurious change to a minimum.

During Phase I of the FRA 1990 Project a large number of forest inventories, repetitive surveys and monitoring studies was studied in detail to produce reliable and compatible pan-tropical forest statistics. This thorough review of existing information permitted a clear definition of the shortcomings of the approaches commonly used in the estimation of forest change.

Table (2.3) 1 below summarises the consistency between two (or more) periodic observations, using three traditional approaches and the approach adopted in the present survey.

Table (2.3) 1: Comparison of various monitoring approaches with reference to the consistency between the historical and recent data

	traditional monitoring approaches			**present approach**
Specific features of each temporal observation	Comparison of unrelated surveys	Comparison of repetitive surveys (same institution)	Single survey based on **independent** analysis of multi-date data	Single survey based on **interdependent** analysis of multi-date data
Classification	NO	YES	YES	YES
Remote sensing data, resolution, scale	NO	Y / N	YES	YES
Season of acquisition	NO	Y / N	Y / N	YES
Interpreter	NO	NO	Y / N	YES
Class delineation	NO	NO	NO	YES

YES = consistency between historical and recent observations
NO = lack of consistency between historical and recent observations
Y / N = Not implicit in the approach; consistency between historical and recent observations varies case by case

The outcome of this review was that the most important element affecting the consistency of data sets, i.e., forest cover at date one and at date two, was how the data sources (satellite images, aerial photos) were related during the process of estimating the changes. The distinction between the characteristics and variations of land cover (object of study) and that of the satellite data used (instruments of the study) is best made when the two images are compared at every stage of the interpretation and subjected to a true/false judgement; assumptions based on one image are verified with the second image, weak evidence on one side could prove to be significant if confirmed on the other side. The information content of each satellite image, from being absolute, becomes relative.

In principle, this analysis could be carried out digitally as well as visually but in practice the digital approach is not yet able to cope with subtle variations in each image due, for example, to haze and shadows or seasonal variations in vegetation appearance. The advantages of being able to compare the two data sources and effect continuous relative adjustments made the visual approach the most suitable method of operational pan-tropical survey. Moreover, it was the most appropriate approach in terms of cost-effectiveness and timeliness.

However, an important question was: how can the subjectivity of class delineation be controlled?

Subjectivity is unavoidable in visual image interpretation. Such subjectivity in classification is particularly strong in classes with poorly contrasted boundaries. In fact, independent interpretations of two different images covering the same area will always present differences (or variability in class delineation) that do not represent real changes. This subjectivity alone, assuming that there is a high level of consistency among all other factors, might introduce sufficient "false changes" to make the monitoring results unreliable.

During the preparatory phase of the pan-tropical survey, with the purpose of identifying the most suitable visual interpretation procedure, three different approaches were tested on a selected site in Zaire and the results were compared . The results of this study, described in the Project Paper: "Interpretation of High Resolution Satellite Data and Compilation of Results for Forest Cover State and Change Assessment; Test Site: Zaire" (R. Drigo, 1991) are summarised in Annex 6.

The outcome of this study was the design of an operational methodology for forest cover monitoring described in detail in the Field Document entitled "Procedure for Interpretation and Compilation of High Resolution Satellite Data for Assessment of Forest Cover State and Change", Forest Resources Assessment 1990 Project (R. Drigo, 1991). The distinctive feature of the methodology is the **interdependent** interpretation procedure. Following this procedure, two images, acquired some ten years apart, are interpreted within a single interpretation process.

According to this approach, each class boundary is based on both images, thus eliminating any relative subjectivity in class delineation between the two images. Consequently, the changed areas are treated like other interpreted classes and have not been derived from the difference between two independent interpretations.

The interdependent interpretation procedure, shown in Figure (2.3) 1, can be summarised as follows:

1 The image showing better quality and interpretability, here called Image 1, is interpreted on a transparent overlay (Overlay 1), which is placed on top of the image.

2 The second image (Image 2) is then inserted between Image 1 and Overlay 1. A new overlay (Overlay 2) is placed and fixed on top of Overlay 1.

3 The interpretation of Image 2 is carried out on Overlay 2 with continuous reference to Overlay 1, as follows:

    3.1 When the class boundary of Overlay 1 fits Image 2 it means that there are no changes and the same line is repeated over Overlay 2.

    3.2 When the line of Overlay 1 does not fit Image 2 it means that there is a difference (not necessarily in land cover); the two images are therefore compared directly. Two outcomes are possible:

        3.2.1 The line on Overlay 1 was wrong; there are no real changes in land cover. Overlay 1 is therefore corrected and the same line is drawn on Overlay 2.

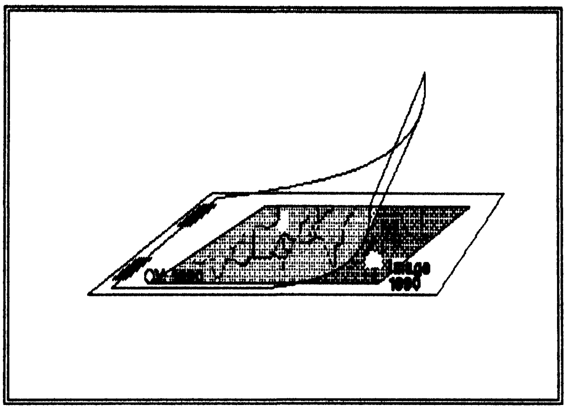
        3.2.2 There is a real change in land cover. A new class boundary is drawn on Overlay2 according to the features of Image 2.

The interpretation is carried out on both images with the production of two overlays, one for the recent image and one for the historical image. All lines correspond perfectly except where a class change has been detected.

Figure (2.3) 1 : Interdependent Interpretation Procedure

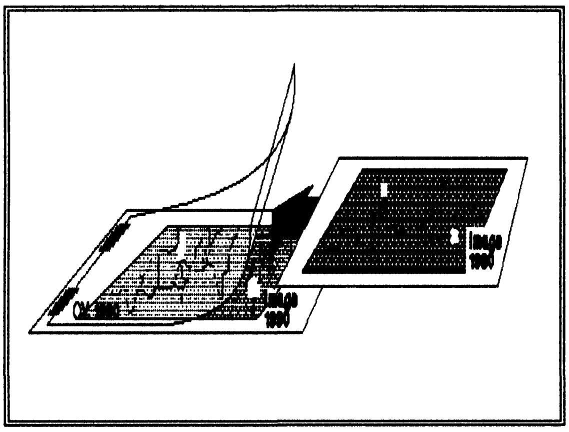
Step 1

Interpretation of 1990 image on a trasparent film overlay (1990 overlay).
The interpretation includes the delineation of Land Cover Classes (black lines) and control features (green lines).



Step 2

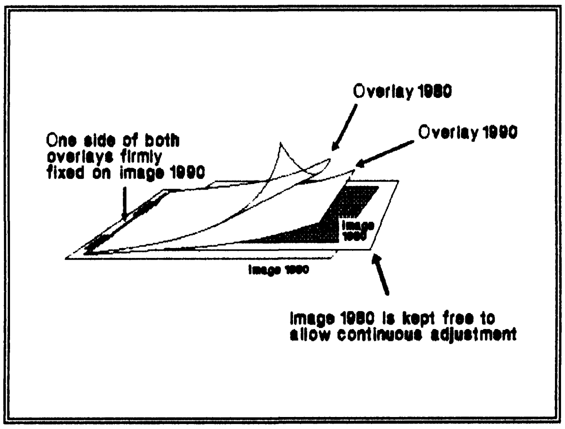
Insert 1980 image between 1990 image and 1990 overlay. Use the green control features to adjust the position of 1980 image to fit the 1990 overlay.



Step 3

Interpret 1980 image (in blue on 1980 overlay) using the delineation on the 1990 overlay as a reference.

Check and adjust constantly the position of the 1980 image with respect to the control features marked on 1990 overlay.


Overlay 1980
One side of both overlays firmly fixed on image 1990
Overlay 1990
Image 1990
Image 1980 is kept free to allow continuous adjustment

The result of the interpretation process will be:

- Spatial co-registration of the two overlays according to the projection of the 1990 image.
- Complete interpretation of the two images without relative subjectivity in class delineation.
- Each line on each overlay is supported by the analysis of **both** images for the classes that have changed as well as for those that have remained constant.

The repetition of all unchanged class boundaries may seem redundant but it has been proved that only a thorough visual analysis permits the detection of all changes. Identifying and drawing the changes only through a visual scanning process tends to produce a systematic underestimation of changes, especially on images with highly fragmented patterns.

The continuous comparison of the two images increases the consistency and reliability not only of the changed but also of unchanged areas; often, while interpreting the second image, the need of modifying the interpretation of the first image arises, owing to new evidence. It can be concluded that, similar to the benefits of stereoscopy which increases the information content of two aerial photos taken from two different points in space, the combined "chronoscopic" use of two images taken at two points in time adds information to both images by showing the "behaviour" of both land cover and satellite imaging.

The effect of the interdependent interpretation procedure on the measurement error for both forest state and change estimates, as compared to the more conventional independent approach, is discussed in Section 4.4 "Evaluation of errors".

An important effect of the interdependent interpretation procedure, in addition to the "thematic" co-registration of land cover classification, is the **geometric co-registration** of the resulting interpretation overlays.

In most cases, the historical and recent (analogue) images presented differing geometric corrections that produced, in spite of their common scale, considerable distortion between the images. In some cases this problem could have been avoided (cost and time constraints permitting) through digital co-registration of the satellite data but in many cases this solution was not practicable since the digital tapes of many historical images were unusable owing to obsolete data formats or to data loss (demagnetised tapes).

Relative geometric distortion is a problem that, if not properly solved, could seriously affect the validity of the resulting transition matrix[1] , which requires perfect spatial correspondence between the two interpretations. In the procedure of interpretation adopted, the recent image has been taken as geometric reference and the historical interpretation overlay has been designed to match it perfectly through continuous adjustment of the historical image to the recent overlay. This process was necessary in order to ensure that the image-to-image comparison was carried out on exactly the same area, in spite of any relative distortion.

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[1] The ***transition matrix***, called also ***change matrix***, records the area of each class at the two dates for which interpretation was done. Table (4.1) 1, in Section 4.1 reports an example of change matrix resulting from the interpretation of one Sampling Unit.

2.4 COMPILATION OF INTERPRETATION RESULTS AT SAMPLING UNIT LEVEL

The system of compilation and analysis at sampling unit level has been designed to produce two basic sets of statistics:

1. **State assessment** results: area by class from the entire recent image.
2. **Change assessment** results: area transition matrix (hereafter called change matrix) from the visible area common to the historical and recent images.

The following considerations ought to be kept in mind:

- It is essential that the interpreter consult and verify immediately the statistics resulting from the interpretation exercise (area by class, transition matrix, deforestation rate, etc.) to detect possible errors in interpretation or data input while the images are still "on the table" and appropriate correction measures can be taken.
- The interpreter should also be responsible for the entry of the interpretation results since he is the only person who is competent to fill in possible missing class codes, which is common, or close incomplete polygons.
- In view of the above remarks and considering that the interpretation and sampling unit analysis are carried out in tropical developing countries by foresters/interpreters from national institutions (not by cartographers or computer experts), the compilation system has to be simple, unsophisticated and based on widespread software that requires very basic hardware (notwithstanding the precision and depth of the results).
- In order to produce reliable transition matrices the compilation system must ensure perfect spatial correspondence between historical and recent classifications without the use of sophisticated equipment.
- The compilation system must be based on standard and well-documented procedures and computer programs, in order to ensure full consistency among the results produced by the various cooperating institutions throughout the tropics.

While the calculation of area is a relatively simple task that can be carried out in various ways through independent counts (by dot grid or planimeter), the compilation of the change matrix is possible only if there is a precise spatial relationship between the 1980 and 1990 data sets that allows the assessment of the same location on both dates. However, the need for a standard format and procedure to be used in developing country conditions made the use of a Geographic Information System (GIS) impractical in this phase of the survey.

The alternative solution was a system designed to run on standard Personal Computers (IBM compatible) using common spreadsheet software (LOTUS 123®), in combination with a dot grid of convenient size.

The system uses a dot grid on stable transparent film with 8 mm spacing where each dot, at the scale of 1:250,000, represents 400 hectares. The grid has a size of 100 x 100 dots (80 x 80 cm) in order to cover completely a full image at the scale 1:250,000. The dot spacing used represents a compromise between accuracy and convenience, the former increasing with the density of dots, and the latter resulting from practical aspects such as the time and difficulty of data recording.

Area measurement by dot grid is a systematic sampling procedure where each dot is the centre of a hypothetical square of given area. An error arises, however, because dots adjacent to a boundary do not represent the entire area of such a square. The percentage error tends to increase with the irregularity of the class boundary but diminishes with the number of dots counted. Since there is no bias introduced by the use of dot grid it is considered that this error, for aggregated results, is negligible (see Section 4.4 "Evaluation of errors" for further discussion).

The dot grid has column and row identification numbers that allow the unique identification of each dot which corresponds to a cell of a computerised spreadsheet file where the column and row identification numbers are also given.

The Compilation System Flowchart, shown in Figure (2.4) 1, summarises the data entry and processing phases for one sampling unit. A detailed description of the compilation procedure, file coding system, files and programs used is given, as step-by-step instructions, in Field Document "Procedure for Interpretation and Compilation of High Resolution Satellite Data for Assessment of Forest Cover State and Change" (R. Drigo, 1991). This document, translated into three languages, has been used as the main reference manual in regional workshops and numerous training sessions.

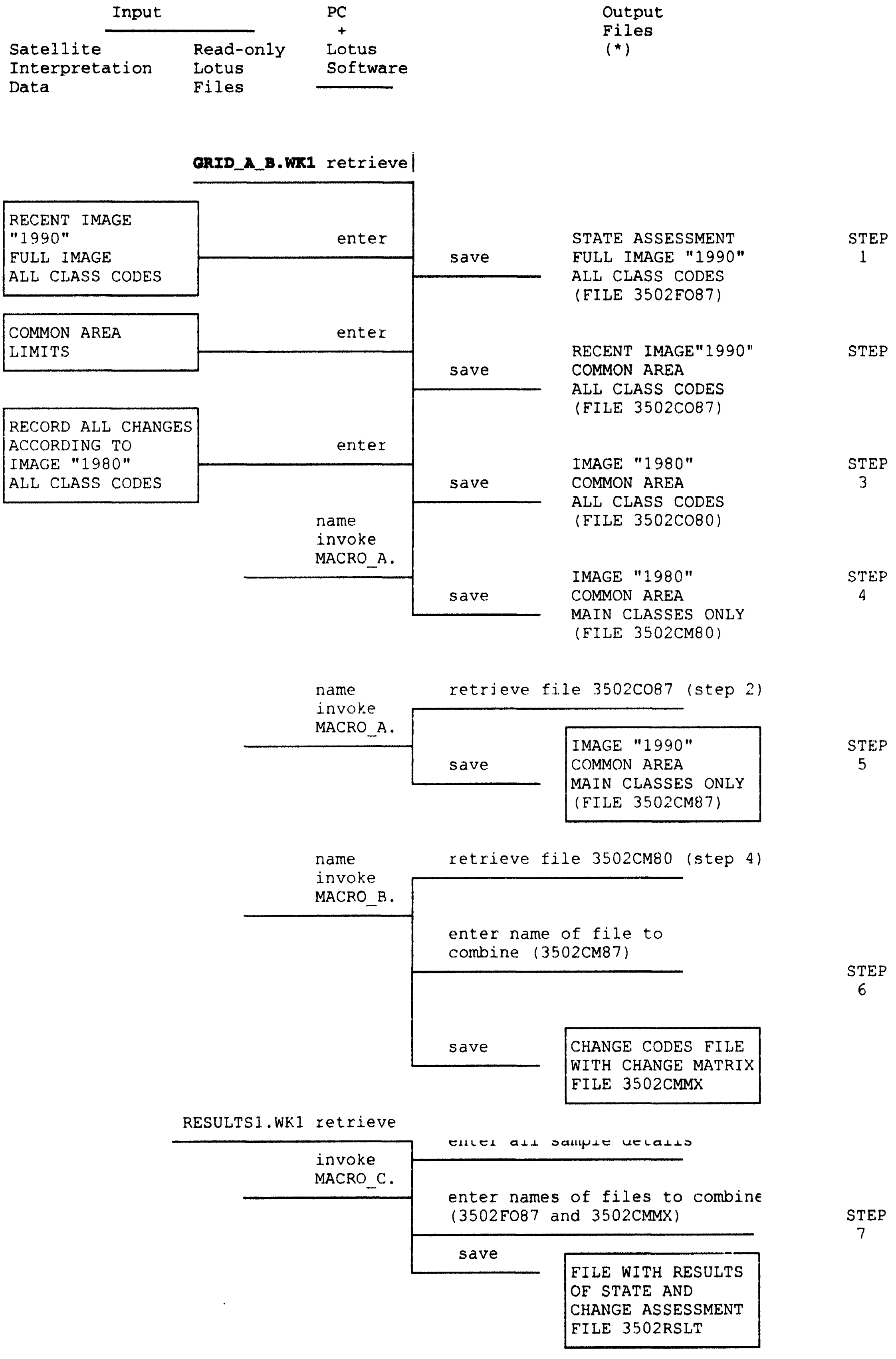
When the data entry is completed for both the recent and historical images the two spreadsheet files created differ only for the classes which have changed during the intervening period between the images. From these two original files two new files are then created by collapsing all Additional Class codes to Main Class codes (codes from 0 to 9). These last two files are then processed to produce one "change file" showing one hundred unique codes that represent all possible combinations of the original ten classes. These unique change codes are created by multiplying all codes of the historical by one hundred and then by subtracting to them the value of the corresponding cell of the recent image. The result of this simple process is the "change file" which is then compiled in the form of a transition matrix, or change matrix, showing all class areas that remained unchanged (along the diagonal) and all the observed class-to-class transitions.

The outcome of the described compilation system, viz, the "result file", includes, in addition to the two sets of data mentioned above i.e. **state** and **change** statistics, a detailed presentation of monitoring results based on the change matrix. These results describe the observed changes that occurred to the land cover categories according to the key to matrix interpretation presented under Section 2.2.1. By analysing the "result file" giving class areas, change matrix, deforestation and degradation rates, etc., the interpreter is able to verify their validity (or to carry out the necessary corrections) and to conclude the estimation process at sampling unit level.

An example of a standard "result file" is presented in Annex 11, for a particular location in North East India. A more thorough discussion of the same Sampling Unit is available in Section 4.1.

The spreadsheet files containing the class codes of both recent and historical images are subsequently used as input to produce simple raster maps with a 400-hectare pixel size, as discussed in Section 2.7 of the present report.

Figure (2.4) 1: Compilation System Flowchart

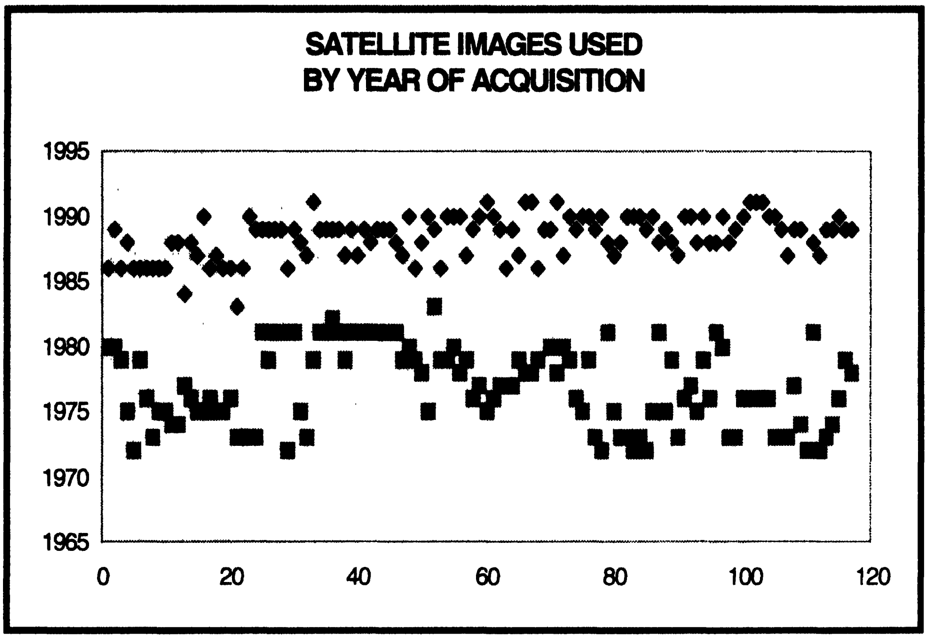

Input
Satellite Interpretation Data
Read-only Lotus Files
PC + Lotus Software
Output Files (*)
GRID_A_B.WK1 retrieve
RECENT IMAGE "1990" FULL IMAGE ALL CLASS CODES
enter
save
STATE ASSESSMENT FULL IMAGE "1990" ALL CLASS CODES (FILE 3502F087)
STEP 1
COMMON AREA LIMITS
enter
save
RECENT IMAGE"1990" COMMON AREA ALL CLASS CODES (FILE 3502C087)
STEP
RECORD ALL CHANGES ACCORDING TO IMAGE "1980" ALL CLASS CODES
enter
save
IMAGE "1980" COMMON AREA ALL CLASS CODES (FILE 3502C080)
STEP 3
name invoke MACRO_A.
save
IMAGE "1980" COMMON AREA MAIN CLASSES ONLY (FILE 3502CM80)
STEP 4
name invoke MACRO_A.
retrieve file 3502C087 (step 2)
save
IMAGE "1990" COMMON AREA MAIN CLASSES ONLY (FILE 3502CM87)
STEP 5
name invoke MACRO_B.
retrieve file 3502CM80 (step 4)
enter name of file to combine (3502CM87)
STEP 6
save
CHANGE CODES FILE WITH CHANGE MATRIX FILE 3502CMMX
RESULTS1.WK1 retrieve
enter all sample details
invoke MACRO_C.
enter names of files to combine (3502F087 and 3502CMMX)
STEP 7
save
FILE WITH RESULTS OF STATE AND CHANGE ASSESSMENT FILE 3502RSLT

File names refer to Sampling Unit 3502

2.5 ANALYSIS OF CHANGE MATRICES

The results of the analysis of any individual sampling unit consist of (i) the areas of land cover classes at two separate times, defined by the dates of acquisition of the satellite images used; and (ii) the class-to-class changes observed for the interim period, in the form of a change matrix. In spite of giving priority to the acquisitions of 1980 and 1990, only a few suitable images were available from those particular years, the majority of them having been acquired some years earlier or later, as shown in the scattergram in Figure (2.5) 1 .

Figure (2.5) 1: Temporal distribution of recent and historical images of the 117 sampling units



The varying years of acquisition of the Landsat scenes and varying intervening periods, prevented the direct inclusion of the original results into a homogeneous database for global and regional estimates. In order to be globally compatible, each set of results required a "temporal adjustment", or standardisation, to the years 1980 and 1990.

If referring only to the variable *forest cover 1980* and *1990*, the adjustment is quite simple to carry out, by interpolating/extrapolating data on the basis of observed annual rates of change. This method of adjustment, however, cannot be applied to change matrices. At the same time it was considered of great importance that not only a few variables be standardised but the information content of the whole matrix, in order to allow aggregation and detailed analysis of change processes at regional and global levels.

This challenging task, as well as other analytical topics, has been the object of cooperative studies undertaken with the Swedish University of Agricultural Sciences (SUAS). The standardisation of the change matrices was finally accomplished through a mathematical method called "diagonalization" which is discussed in the Project paper "Estimates of Tropical Forest Cover, Deforestation and Matrices of Change" (E.Rovainen, PhD thesis, SUAS, 1994), summarised in Annex 7 and described briefly below.

1. The original *n*-year area matrix has been transformed into the ***n*-year transition probability matrix**; this has been done, row by row, by dividing the value of each cell by the "historical" total area of the class. The result is a transition matrix giving the probability that each historical class would remain stable or would change into any other class during the period observed.

2. The **annual transition probability matrix** is calculated from the n-year probability matrix through diagonalization.

3. Similarly, the **10-year transition probability matrix** is calculated from the annual probability matrix.

4. The **class areas in 1980** are estimated by applying the annual probability matrix 1980-*t* times to the classes of the historical image, where *t*=year of historical image.

5. The final **1980 - 1990 area transition matrix** is then calculated by applying the 10-year probability matrix to the 1980 class areas.

Applied to all sampling units, the process of standardization produced a set of estimated change matrices covering comparable time periods and carrying the full information content of the original results.

2.6 PAN-TROPICAL DATABASE OF CHANGE MATRICES

The change matrices, original and standardized, represent a unique set of data on the land cover dynamics in the tropics. They represent the first consistent estimates of transition rates among nine relatively detailed tropical forest and other land cover classes between 1980 and 1990 that used compatible methods, compatible time periods and compatible definitions. Their value goes well beyond the scope of the present report and they represent only the first round of a continuous and evolving programme. The matrices can be aggregated or post-stratified under various viewpoints to provide revealing insight on the land cover change processes in the tropics.

For the present reporting purposes, it was considered necessary to aggregate and analyse the change matrices by ecological zone and by geographical region.

In addition to the three regions of **Tropical Africa, Tropical Latin America and Tropical Asia**, which represent the simple aggregation of the original sub-regions, the post-stratification was conducted on the basis of the following broad ecological zones, defined on the basis of rainfall:

Z1 - Wet and Very Moist (rainfall > 2000 mm)

Z2 - Moist (with short and long dry seasons) (rainfall of 1000-2000 mm)

Z3 - Sub-Dry to Very Dry (rainfall of 200-1000 mm)

Drier conditions with rainfall below 200 mm, such as Semi-arid and Arid zones, were implicitly excluded from the sampling universe in view of their lack of forest cover (see Section 2.1.1 "Sampling design").

The main climatic characteristics of the ecological zones used are given in Annex 16, while their geographic distribution are shown in three regional maps in Section 4.2.3 "Ecological level results".

The process of post-stratification was carried out according to classical statistical methods for sample survey that consider unequal probability of inclusion as follows:

1. The standardized change matrices were individually de-weighted according to the sampling fraction adopted in the original stratification.

2. The de-weighted matrices were aggregated according to the new stratification criteria.

2.7 SPATIAL OUTPUTS

The first and most important spatial output of the survey was the set of interpretation manuscripts resulting from the analysis of each sampling unit. These manuscripts, drawn on stable transparent film (hereafter called interpretation overlays), contain class codes and class delineation, and are the result of interdependent visual interpretation of historical and recent images. As a result of the interpretation approach both overlays, historical and recent, are co-registered to the scale and projection of the recent satellite image.

Map specifications of the interpretation overlays

Scale: 1:250,000
Projection: Variable, usually Space Oblique Mercator (SOM), in all cases that of the recent "system corrected" Landsat image used in the sampling unit
Minimum mapping unit: 3 x 3 mm for isolated classes
2 mm width for linear features

In order to be used effectively in further spatial analysis, or simply for map production, these manuscripts must be converted into digital format and imported into a Geographical Information System (GIS). For the purpose of producing digital maps two different approaches have been followed:

Production of **raster maps** from spreadsheet files
Production of **vector maps** from original manuscripts (interpretation overlays)

These two options are quite different in terms of time, cost implications and outputs. The production of raster maps is simple and inexpensive but of lower spatial resolution while the production of vector maps is rather expensive and time consuming but maintains the full spatial resolution of the original manuscripts. From the point of view of thematic aspects such as classification and class-to-class transitions the two outputs are equivalent in maintaining full "thematic resolution".

In view of the additional time and costs involved, the production of vector maps has only been initiated in selected areas along with the development of the most convenient vectorizing procedures. On the contrary the production of raster maps has been carried out systematically both for state and change maps and used during the phases of evaluation and validation of sampling units results.

Production of raster maps

As described in Section 2.4, for each SU a set of spreadsheet files was produced as result of the data entry by means of a dot grid. In addition to their use as input for the statistical analysis and further elaboration already described, these files were suitable to originate spatial information since the spatial relations among the 10,000 coded cells contained in each file truly represented the spatial features resulting from the interpretation of the satellite images. However, as a result of using a dot grid where each dot represents a square of 2 x 2 km, the map information is limited to a systematic sampling of the original class delineation with a 'pixel size' of 400 hectares.

This process of transformation from spreadsheet to raster map was effected by using the IDRISI® GIS package, which is simple and inexpensive, through the following steps:

State maps (historical and recent)

- Production of ASCII files from spreadsheet files.
- Conversion of ASCII files into row raster maps using the IDRISI module SSTIDRIS.
- Use of module ASSIGN to produce standard images and color codes using a pre-defined attribute file.
- Addition of a standard legend.

Change maps

- Cross classification of historical and recent images using the module CROSSTAB.
- Analysis of the resulting class transitions and reduction to a standard set of change classes according to a pre-defined reference table.
- Addition of a legend of standard change categories.

The one hundred possible class transitions (including here also the "non-interpreted" class) have been consolidated, in a convenient color display, to 15 categories of change as shown in table (2.7) 1 below, following the principles discussed under Section 2.2.1 "Definition of forest and forest area changes".

Table (2.7) 1: Categories of change used in the legend of the raster change maps

	Classes at date 2									
Classes at date 1	**closed forest**	**open forest**	**long fallow**	**frag-mented forest**	**short fallow**	**shrubs**	**other land cover**	**water**	**planta-tions**	**Non-interpre-ted**
closed forest	7	4	4	2	1	1	1	1	6	14
open forest	11	7	4	2	1	1	1	1	6	14
long fallow	11	11	7	2	1	1	1	1	6	14
fragmented forest	12	12	12	8	3	3	3	3	10	14
short fallow	13	13	13	12	9	5	5	5	10	14
shrubs	13	13	13	12	10	9	5	5	10	14
other land cover	13	13	13	12	10	10	9	9	10	14
water	13	13	13	12	10	10	9	0	10	14
plantations	6	6	6	5	5	5	5	5	9	14
non-interpreted	14	14	14	14	14	14	14	14	14	14

Code	Legend of Change Maps
0	Stable water
1	Deforestation
2	Fragmentation
3	Partial deforestation
4	Degradation
5	Decreased biomass
6	Forest <=> plantation
7	Stable forest
8	Stable fragmentation
9	Stable non-forest
10	Increased biomass
11	Forest amelioration
12	Partial afforestation
13	Natural afforestation
14	Non-visible

An example raster maps of land cover state and change is presented in Section 4.1 as one of the products of individual sampling unit analysis.

Raster maps are being progressively transferred into the FRA 1990 Geographic Information System (GIS) in order to allow their integration with all other map layers of the project. The process of integration of the IDRISI raster maps into the GIS requires the completion of several transformations aimed at defining map coordinates and rotating them according to satellite orbit inclination. The main steps summarized below describe the automated standard approach followed in the absence of control points (G. Muammar, 1994) :

- Using the original spreadsheet files the center of the interpreted area of the raster is calculated in pixel coordinates (100 x 100 pixels). This is to be used as a control point in relation to the known nominal center of the image (latitude/longitude).
- Using IDRISI modules the raster was resampled to 8 times its size (800 x 800 pixels). This ensures that distortion due to the automatic resampling that occurs in the following steps will be minimized.

- Using dBase the rotation of the five control points (the center and four corner points of the raster) were calculated using the following formula:

  $new\ x \quad x \cdot \cos(\alpha)\ y \cdot \sin(\alpha)$ **and** $new\ y \quad x \cdot \sin(\alpha) + y \cdot \cos(\alpha)$

  where α (angle of inclination of the image) $\arcsin\{\sin(\mathbf{8.2})/\cos(latitude)\}$
- Again with IDRISI, the rasters were rotated as a linear transformation supplying the five control points and their new coordinates.
- The rasters were imported into FRA 1990 Project's GIS (SPANS® and ARCINFO®), relating their center in pixel coordinates to the latitude/longitude of their nominal centers for geo-referencing.

Other techniques of geo-referencing the raster maps have been tested for two sampling units (Peirsman, 1994) . These techniques include (i) image to map, used as main reference for technique comparison; (ii) using corner point locations; and (iii) using a vector file location of corner points. The latter technique proved to be more accurate where accurate control point coordinates were available.

After checking the results of the transformation with reference GIS control features, the first grade approximation of the standard geo-referencing technique appeared to be acceptable in view of the coarse resolution of the raster maps. These maps are in fact more suitable for integrated statistical analysis and spatial models than for cartographic applications.

Production of vector maps

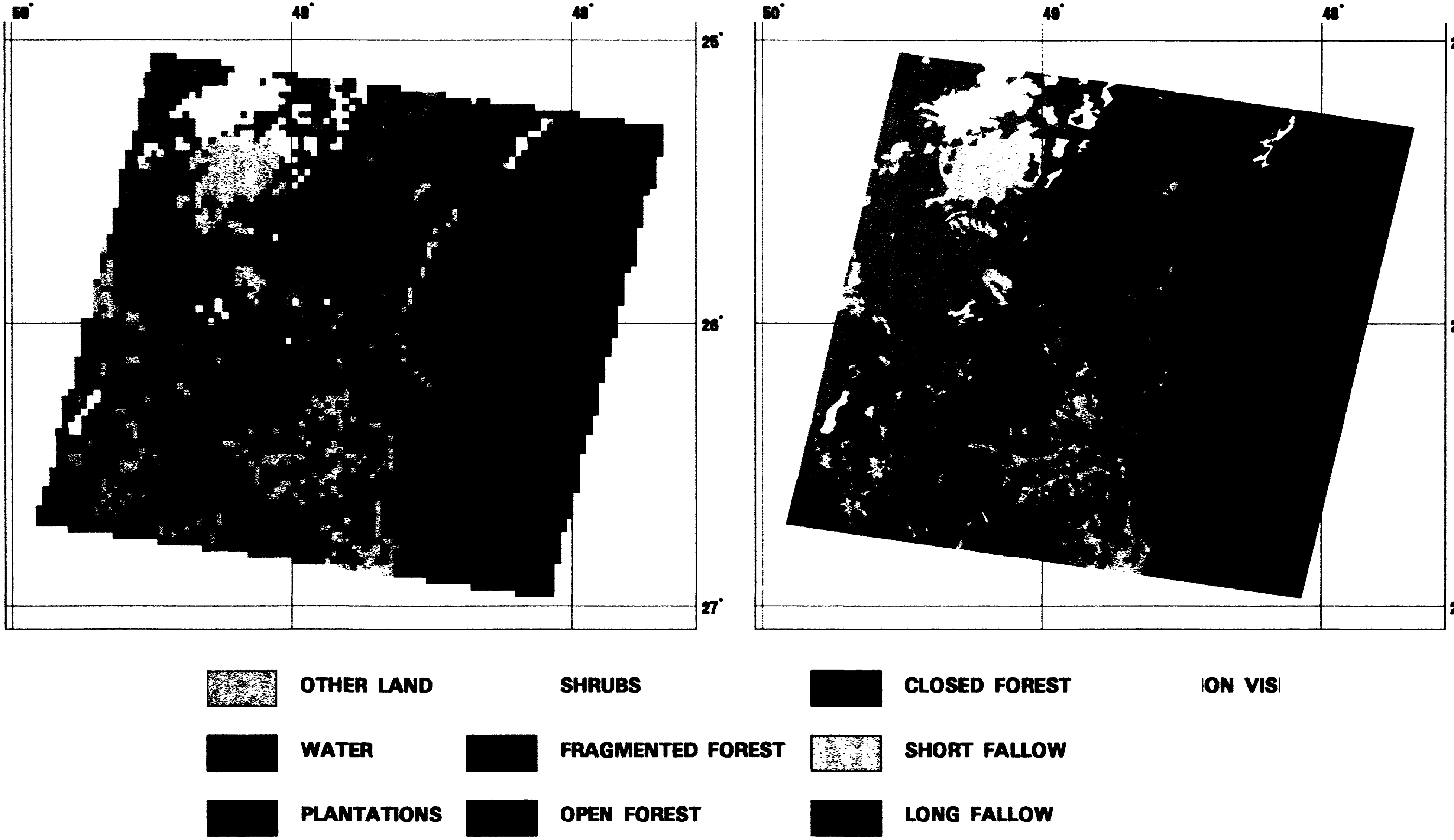
As stated above the statistical analysis and spatial representation of state and change of forests has been achieved, without loss of thematic resolution, by means of the raster maps. Nevertheless, spatial studies related to the analysis of "within-sample" processes might require a resolution higher than the one associated to the raster maps: i.e. landscape ecology studies dealing with spatial features, like shape, size, complexity of land cover features would produce more reliable output if based on the original 1:250,000 scale data.

In general terms, GIS applications oriented to "within-sample" studies would benefit from using high resolution data in a multi-layered analysis framework. In view of the above mentioned aspects, conversion of interpretation overlays has been initiated. A procedure was implemented to maximize the accuracy/cost ratio, involving the following steps:

- Transfer of linear features, namely cover types boundaries, with no labels, onto clean transparencies (china ink - pensize 0.3 mm.)
- identification, with the help of existing maps and the original satellite imageries, and drawing on the transparencies, of ground control points (GCPs).
- Scanning of the new transparencies at 200 dots per inch (dpi) resolution, thus producing 30 meters resolution rasters.
- Raster-to-vector conversion and clean-up editing.
- Assignment of the cover types identifier to each polygon.
- Conversion of the digitizing unit map into geographic coordinates via GCPs.

Figure (2.7) 1 shows the raster and vector maps derived from the same interpretation overlay of SU 3517, located in the south Brazilian State of Santa Catarina; this example shows the considerable gain in spatial resolution deriving from the vector approach. This approach is currently operational for the transformation of recent interpretation overlays into the FRA1990 GIS databases. The conversion of historical interpretations is in a prototype phase in order to evaluate the most efficient way to store and retrieve changes as well as historical and recent data.

Figure (2.7)1: Example of raster (left) and vector (right) maps.
Sample 3517 – Santa Catarina, south Brazil – 1988 acquisition



2.8 BIOMASS CHANGE ANALYSIS

The estimation of the state and change of land cover classes is expressed as a bi-dimensional value such as area, area by class and area transition matrix. A transition of one million hectares from *closed forest* to *other land cover* is equal, in terms of area, to a transition of one million hectares from *closed forest* to *open forest*, except for an arbitrary conceptual categorization which tells us (if we so decide) that the first represents ***deforestation*** while the second represents ***degradation***. One's way of perceiving this distinction remains subjective and descriptive, no matter how logical and documented, since the ***concept*** supporting it can be described but not measured.

Linking these conceptual elements (class, transition category) to a measurable parameter can serve the purpose of enriching the ambiguous level of conceptual subjectivity, expressed by the *meaning* we give to the various elements, with an element of quantitative comparability. A quantitative parameter such as **biomass**[1] can provide this clarifying third dimension to the area results. The mean biomass value for a given class and the estimated biomass value gained or lost in class transition have absolute dimensions irrespective of how we categorize them.

The "biomass perspective" is a very interesting one in the analysis of land cover dynamics since it creates an unambiguous ranking system and it provides a quantitative estimation of the environmental impact of the changes such as the release or sequestration of woody biomass-related carbon.

The main problem consists in identifying reliable mean biomass density values to be allocated to each land cover class. In addition, the biomass value for a given class varies with specific site conditions.

Biomass data as such have been rarely measured in the field; most of the biomass information presently available derives from stand tables (the number of trees by diameter classes) and stemwood volumes which are typically measured and reported in forest inventories. Reliable methods have been developed for converting this available forest inventory information into biomass density estimates (Brown et al., 1989; Brown and Lugo, 1992; Gillespie et al., 1992; Brown and Iverson, 1992).

Volume-to-biomass conversion equations have been used in the FORIS database to estimate average country-level biomass densities for the main forest formations, viz. closed forest and open forest (sensu FORIS). Biomass density estimates have been related spatially and statistically to biophysical parameters, vegetation maps, population density data, etc., to produce forest biomass maps (Peninsular Malaysia, Brown et al., 1992; Continental South/Southeast Asia, Iverson et al., 1992; Africa region, Lorenzini, 1994).

The average biomass densities by main forest formation, produced in the studies above, have been correlated with ecological zoning and used to infer biomass values for the nine land cover classes for each zone. In some specific cases, such as the analysis of results of sampling unit 4409 located in north east India, discussed in Section 4.1, the class biomass values have been inferred from biomass estimates derived applying conversion equations to stand tables available from the exact study area. However, since no direct biomass measurement has so far been made in relation to the land cover classification here adopted, all estimates produced should be considered as indicative.

In the inference method followed to produce class biomass densities the available biomass values by main forest formation (from FORIS database and Biomass Maps) have been adjusted, on account of classification differences, to determine *closed forest* and *open forest* indicative values. In turn, values for *long fallow* and *fragmented forest* classes have been derived from the previous two classes on the basis of forest fraction and forest type of origin. The values for the remaining classes have been guesstimated as fractions of the relative closed forest value, used in this case as an indicator of productivity.

The main use for biomass values thus determined has been the positioning of the land cover classes along the Y axis of the woody biomass flux diagram developed in this study (see diagrams in sections 4.2.1, 4.2.2, 4.2.3). This diagram helps to visualize the biomass implications of class-to-class area transitions, to better understand the environmental toll of the various change processes and to compare them by ecological zone. A further contribution could be an indicative quantification of biomass loss and gain.

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[1] The data sources used for the present study define biomass as: the total above ground biomass density of trees of 10 cm diameter (breast height) or larger, including main stems, branches, bark, twigs, leaves and fruits. In the present study an attempt has been made to guesstimate the biomass of woody vegetation at less than 10 cm diameter, such as that of shrubs and young secondary regrowth.

A more detailed quantification of biomass changes can be produced for the areas where sufficiently reliable biomass estimates are available. An example of such analysis is given in Annex 11 for one sampling unit located in North East India.

Table (2.8) 1 gives the inferred biomass values that have been used in the Woody Biomass Flux Diagrams shown in this report which describe the change processes at pan-tropical and ecological zone levels.

Table (2.8) 1: Indicative biomass density values by land cover class and ecological zone.
Tonnes per hectare

	Ecological Zone			**ALL ZONES**
Cover Classes	**Wet and Very Moist**	**Moist with Short and Long Dry Season**	**Sub-Dry to Very Dry**	(global mean)
Closed Forest	300	200	120	225
Open Forest	100	80	60	90
Long Fallow	130	70	50	80
Fragm. Forest (*)	33 99	26.4 66	19.8 39.6	60
Shrubs	50	30	15	40
Short Fallow	40	20	10	30
Other Land Cover	10	5	3	7
Water	0	0	0	0
Plantation	150	100	100	110

(*) Biomass of fragmented forest, estimated at 33% of *continuous* forest biomass, depends on the forest class of origin (closed or open forest).

Indicative estimates of the biomass "gradient" in each possible class transition (the difference between biomass in class of destination and class of origin) for the three ecological zones are given in Annex 8. This gradient, allocated to all possible class transitions, provides an interesting "third dimension" to class transitions or simple class relations that can be useful in the analysis of other issues, as discussed under section 4.4.3 "Evaluation of errors; classification errors".

Chapter III

Survey Implementation

3.1 SELECTION AND PROCUREMENT OF SATELLITE IMAGES

The identification and procurement of the most suitable set of satellite images for each sampling unit have been complex tasks and certainly the single most time-consuming phase of the survey.

After the locations of the 117 sampling units were selected statistically, as described under Section 2.1, using the World Reference System 2 (WRS 2) of the Landsat Program as a reference, the work consisted of defining the historical image (or images) corresponding to the path and row of the recent image and identifying the best acquisitions among those available for both recent and historical coverage.

The historical images, acquired during Landsat missions 1, 2 and 3, correspond to the World Reference System 1 (WRS 1). The two reference systems do not correspond: with mission 4 (July 1982, the beginning of WRS 2) the number of paths was reduced by about one-tenth; owing to this difference and in order to reach the minimum common land area required of one million hectares, in several cases two historical images had to be used.

Selection criteria

The selection criteria applied in the identification of the best acquisitions were based on the requirements given below, listed by order of importance:

1. Optimum season of acquisition;
2. Good seasonal and nearest calendar day correspondence between recent and historical images;
3. Minimum cloud cover and good radiometric quality;
4. Recent and historical images as close as possible to the years 1990 and 1980, respectively; and
5. Availability.

The **optimum season** corresponds to that in which forest classes (or, more in general, woody vegetation classes) can best be distinguished from other cover classes. The best time for forest/non-forest separation is usually the beginning of the dry season, where such seasonal condition occur. At that time the spectral signature of the tree cover and that of the undergrowth (grass, herbs) present the highest contrast; the grass has already begun to dry while the tree canopy of deciduous formations is still in full leaf. In order to guide the selection, a special search was conducted to define the optimum season of acquisition for each sampling unit and the information gathered was included in a database.

The closeness of **calendar day of acquisition** between historical and recent images is very important for areas with strong seasonal fluctuations and deciduous formations. For the analysis of changes it is essential that both historical and recent images present the same vegetative phase and, consequently, the same appearance.

The **cloud coverage** of historical and recent images combined can reduce considerably the usable area for change assessment, as the common area (the area visible on both images) has already been reduced by the discrepancy resulting from the differing reference systems of WRS 1 and WRS 2. In general a maximum cloud cover of 20 percent was applied when alternatives were available but often the selection was made also in consideration of the location of the clouds (when this precious information was available!) and the size of the common area. The objective was to secure at least one million hectares of visible common land.

An assessment of **radiometric quality** was usually reported in the image catalogues, together with an assessment of cloud coverage . It should be stated, however, that this information was often unreliable or referred only to macroscopic aspects detected on one band only. The presence of haze and band saturation in old acquisitions are normally not reported in the catalogues, which makes the selection of images a sort of gamble as the actual quality is unknown until the image has been received.

In view of the objective of studying the changes for the standard period **1980-1990**, preference was given to the images acquired as close as possible to these two particular years. In the case of a lack of 1980 and 1990 acquisitions and considering that changes become clearer over a longer period of time, the only requirement was that the two images be separated by at least six years.

In the case of **missing suitable data** due to permanent cloud cover or a simple lack of acquisitions, the approach followed was to order the best image available and integrate it with other satellite data (such as SPOT) and/or existing thematic maps. This ultimate solution became necessary for seven sampling units out of 117 and in each case for only one of the two images needed.

The complete list of images finally selected, procured and analysed in the present survey is given in Annex 9. A total of 283 satellite images were studied, of which 116 represented the recent coverage (only one was missing), 148 represented the historical coverage and 19 were additional images used as "second reference" for SUs already complete with recent and historical images.

The procurement of these images was the result of a cooperative network between the FRA 1990 Project and remote sensing data suppliers, receiving stations, data banks and national institutions throughout the world; a complete list of partecipating institutions and individuals is given in Annex 3 "Project Network".

3.2 TRAINING AND DISSEMINATION OF METHODOLOGY

The methodology of interpretation and analysis has been designed for implementation in the real world and particularly under the conditions of developing countries and not in isolation under "controlled" conditions. This feature is reflected in several aspects of the methodology and above all in the procedure of interpretation of the satellite images, compilation and analysis of results at sampling unit level.

The dual purpose implicit in this approach can be summarised as follows:

- Enhancement of countries' capacities in forest resources monitoring. In addition to the global character of the survey, the methodology has been designed to match the average features (visual interpretation, scale, classification) of national resource assessment/mapping activities and to meet national and sub-national level information requirements on land cover dynamics for resource management planning. The monitoring methodology is intended to be an operational and realistic step forward of a high theoretical standard yet simple and unsophisticated in implementation.
- Tapping the knowledge at its source. The most competent persons involved with land use and vegetation cover types, their distribution and how these appear on satellite data are those national officers that are normally responsible for the use of such data for forest resource assessment and mapping. The role of the interpreter is of particular relevance in the interdependent interpretation procedure, which implies the thoughtful "blend" of several layers of information where field knowledge is determinant. Given appropriate training to ensure global compatibility of terms and procedures, the cooperation of national institutions in carrying out the present pan-tropical survey represents the best guarantee of realism and reliability.

In consideration of the above, the FRA 1990 Project has given much importance to and has concentrated great effort on training and the dissemination of monitoring methodology through numerous workshops and training sessions where the methodology has been presented, discussed and applied practically.

Many institutions have been deeply involved in the application of this methodology, mastering its techniques and appreciating its potential at local level.

3.2.1 Regional workshops and training sessions

With the objective of promoting self reliance in forest resource monitoring and guaranteeing reliable interpretation results the project has organized and carried out four regional workshops and several country-level training sessions where forest monitoring methodology and techniques have been presented, implemented and discussed.

REGIONAL WORKSHOPS

		PARTICIPATION		
Location	Date	Persons	Countries	Language
Bangkok	May 1991	17	9 (Asia)	English
Nairobi	November 1991	20	10 (Africa)	English
Mexico City	March 1993	21	10 (Latin America)	Spanish
Yaoundé	March 1994	27	12 (Africa)	French and English

TRAINING SESSIONS

Location	Date	Institution [full names under Table (3.3) 1]
Mexico City, Mexico	February 1991	SARH
Brasilia, Brazil	March 1991	IBAMA
Dehra dun, India	June 1991	FSI
Kinshasa, Zaire	August 1991	SPIAF
Brasilia, Brazil	March 1992	IBAMA
Bangkok, Thailand	April 1992	RFD
Jakarta, Indonesia	April 1992	NFI
Dehra dun, India	April 1992	FSI
Hanoi, Viet Nam	June 1993	FIPI
Jakarta, Indonesia	June 1993	NFI

With the exception of the first workshop in Bangkok, which lasted two weeks, all other Regional Workshops had a duration of three weeks. The training sessions lasted between one and two weeks.

Workshop activities were organized according to the following schedule:

Phase I
- Introduction
- Presentation of methodology :
    - Classification
    - Interpretation procedure
    - Compilation and analysis
- Presentation and discussion of national monitoring activities and other issues

Phase II
- Distribution of multi-date images to each country team
- Implementation of monitoring methodology
    - Inter-dependent interpretation
    - Data entry and processing
- Field activities

Phase III
- Presentation and discussion of sampling unit results by each country team
- Discussion on methodological aspects:
    - Classification
    - Interpretation procedure
    - Compilation and analysis
- Conclusions and recommendations

In order to complete the ambitious planned programme of activities, these workshops always resulted in three weeks of very hard work. There was continuous improvement at each session, especially in the organization of activities and the harmonious balancing of theoretical presentations/discussions with the practical application of the methodology. During the last workshop the activities also included some additional elements of analysis such as the creation of raster maps and an introduction to the standardization of change matrices. This was also possible thanks to the very active participation of the team members from Zaire who were already familiar with the methodology and could thus assist the other participants in all phases of the workshop.

Each workshop concluded with the participants drawing up a set of conclusions and recommendations on the various aspects of the monitoring methodology. These concluding statements, together with a description of workshop's scope, background and agenda, country contributions, activities and results of the sampling units studied were included in four workshop reports. Annex 10 contains some brief presentation sheets, as well as the conclusions and recommendations from each workshop report.

In respect of the three main elements of the methodology, viz, classification, interpretation procedure and compilation system, the conclusions expressed by the participants of the four workshops are rather uniform and can be summarized as follows:

> The FRA 1990 **classification scheme** received a wide range of comments, some calling for the inclusion of more detailed classes and some for a reduction in the number of classes. There seems to be agreement, however, in:
>
> - recognizing the need for a standard classification of woody vegetation based on physiognomic characteristics;
> - considering the present classification adequate to meet its present task;
> - noting that it is necessary to reserve the freedom to subdivide further the standard classes into more specific classes in order to meet national level requirements and that such subdivisions be structured hierarchically in order to allow comparison and consistent synthesis at national, sub-regional, regional and global levels; and
> - emphasizing the important role of field knowledge and image quality in enhancing the reliability of classification results and that, in general, there is scope for improvement in both areas.
>
> There has been general consensus in considering the **interdependent interpretation procedure**:
>
> - adequate to meet the task of change analysis owing to its coherence and logic,
> - beneficial in minimizing the errors of interpretation for the assessment of both forest cover state and change since it allows one to compensate for the poor quality of one of the two images.
>
> It was also noted, however, that the interdependent interpretation could be simplified if the two images were co-registered spatially and free from relative distortion.
>
> An interesting comment was received from Professor Tape Bidi from the University of Ivory Coast. He affirmed that this procedure of interpretation has a strong educational character and should be introduced in university courses since it stimulates the data interpreter to review critically, evaluate and synthesize several layers of information into a unique logical process.
>
> The **compilation system** and the type of results produced received positive comments in view of the following main aspects:
>
> - In its results the class transitions are presented in full detail, in the form of a change matrix, which allows the meaningful analysis of the dynamics.
> - The procedure of compilation, using a dot grid and commonly available software, is simple and does not require sophisticated equipment, which facilitates its diffusion and implementation at local level.

The success of the workshops and training sessions in (always!) completing the analysis of sampling units confirmed that the objectives of adapting to average working conditions were met. Most of the participating foresters/interpreters did not have previous experience in handling computers and software but could master the spreadsheet files and macros easily enough since the assumption that "where there is a Personal Computer there is always someone expert in LOTUS-123®" turned out to be true.

Guidelines, presentation papers and other training material was prepared in three languages (English, French and Spanish) and considerable experience has been acquired in methodology presentation.

Approximately 140 Forestry/Remote Sensing Officers from most tropical countries have been trained in the theoretical and practical aspects of forest resource monitoring. Through these international meetings a network has been established among the participating individuals and institutions on the specific issue of forest monitoring.

3.3 INTERPRETATION AND ANALYSIS OF SAMPLING UNITS

The analysis of the sampling units has been carried out, to the largest possible extent, by national satellite data interpreters from the countries where the sampling units were located. The vast majority of these interpreters are foresters by training, experienced interpreters of satellite images and frequently responsible for national vegetation mapping programmes. Annex 2 and Annex 3 provide, respectively, the list of Remote Sensing Lead Centers, where most image interpretation work was carried out, and that of other direct contributors to the analysis of sampling unit data.

Two different approaches were followed for the interpretation and compilation of the 117 sampling units:

1. Sampling unit analysis was carried out during workshop activities or training sessions after a thorough presentation of methodologies and concepts and under the direct technical supervision of FRA 1990 Project staff.
2. Groups of sampling units were analysed under contractual and/or cooperation agreements with national institutions by selected teams of interpreters who participated, in most cases, in regional workshops and received additional training at country level.

Table (3.3) 1: List of the main contributors to the analysis of the 117 Sampling Units of the Pan-tropical Survey[1]

	SUs analysed at workshops and training sessions	SUs analysed by FRA 1990 Project staff at FAO HQ	Cooperation and Contractual Agreements		
			Institution		Number of SUs
AFRICA	20	5	SPIAF[2]	Zaire	8
			IAO[3]	Italy	26
LATIN AMERICA	10	1	SARH[4]	Mexico	4
			IBAMA[5]	Brazil	17
			Others[6]		6
			IAO[3]	Italy	2
ASIA	5	1	FSI[7]	India	10
			RFD[8]	Thailand	4
			FIPI[9]	Viet Nam	4
			NFI[10]	Indonesia	3
			RSRDA[11]	Philippines	2
			IAO[3]	Italy	5

[1] The total number of SUs in the above table is 133 and not 117 since several SUs have been analyzed twice.

[2] *Service Permanent d'Inventaire et d'Aménagement Forestiers* (SPIAF), Zaire

[3] *Istituto Agronomico per l'Oltremare* (Overseas Agronomic Institute), Ministry of Foreign Affairs, Italy

[4] *Secretaria de Agricultura y Recursos Hidraulicos de Mexico* (SARH), Mexico

[5] *Instituto Brasileiro de Meio Ambiente e Recursos Naturais Renováveis* (IBAMA), Brazil

[6] Javier Anduaga, *Ministerio de Agricultura, Oficina General de Planificación Agraria* (OPA), Peru
Homero Chaccha Córdova, *Instituto Nacional de Recursos Naturales* (INRENA), Peru
Leonardo Lugo and Paulino Ruíz Mendoza, *Servicio Forestal Venezolano* (SEFORVEN), Venezuela
Gerónimo Grimaldez, *Centro de Desarrollo Forestal, Ministerio de Asuntos Campesinos y Agropecuarios*, Bolivia
Raúl Lara Rico, *Centro de Investigaciones de la Capacidad de Uso Mayor de la Tierra* (CUMAT), Bolivia

[7] Forest Survey of India (FSI), India

[8] Royal Forest Department (RFD), Thailand

[9] Forest Inventory and Planning Institute (FIPI), Viet Nam

[10] National Forest Inventory (NFI), Indonesia

[11] Remote Sensing and Resource Data Analysis Dep., National Mapping and Resource Information Authority, Philippines

As is evident from the list of contributors in Table (3.3) 1 the FRA 1990 Project made a major effort to decentralize the work of interpretation and analysis of the sampling units. From the strict point of view of producing results at each sample location, this approach has certainly been uneconomical, given the time needed for coordination, supervision, training and administration. On the other hand, the approach has facilitated the successful dissemination of a standard, consistent and "all weather" methodology to many individuals and institutions and has tapped the most competent sources of field knowledge available.

The role played by Messrs Musampa, Bwangoy and Shoko of SPIAF, Zaire, and Ms Jansen and Mr Lorensi of IBAMA from Brazil, who became so experienced in the methodology that they were able to act as trainers during regional workshop activities, is of particular relevance.

In spite of the two workshops carried out and the positive contribution of SPIAF, the analysis of the African sampling units could not be decentralised totally due to difficulties encountered in travelling to the countries, in establishing links with national institutions and in providing the necessary training. All these "difficult" cases in Africa and, to a lesser extent, in the other regions, have been studied and finalized within the framework of the cooperation activities with the *Istituto Agronomico per l'Oltremare* (Overseas Agronomic Institute) of Florence, Italy and in particular thanks to the contribution of Ms Angela Dell'Agnello and Ms Ilaria Ambrosini.

The interpretation of satellite data was always carried out with the support of, and with reference to, descriptive reports, including ground photographs, whenever available, and existing cartographic information such as vegetation, forest type, eco-floristic and land use maps; these references were essential when the interpreter was not sufficiently familiar with the field conditions, and proper field verification could not be carried out. This information was mainly used to support decisions on those physiognomic aspects of vegetation that cannot be estimated only on the basis of tone and texture, such as canopy height, to differentiate *forest* classes from *shrubs*, or the lower crown densities, to separate *open forest* from *other land cover.*

3.4 FIELD VERIFICATION

Field verification at sample locations could not be carried out systematically due to the high costs involved and to inaccessibility of a sizeable number of such locations. Field verification has therefore been restricted to a fraction of the sampling units on the basis of (i) importance of ground truth as a function of classification complexity and available knowledge; (ii) accessibility, logistics; and (iii) financial resources.

Table (3.4) 1 reports the status of field knowledge of the present survey by region and ecological zone.

Table (3.4) 1: Levels of field knowledge that supported the interpretation of satellite images
Values are the number of SUs and percentages within ecological zones.

	Wet			Moist			Dry			All Zones		
	Verif.	Famil.	Refer.	Verif.	Famil.	Refer.	Verif.	Famil.	Refer.	Verif.	Famil.	Refer.
Africa	0	0	3	5	6	17	1	1	14	6	7	34
Lat. America	0	4	7	6	12	6	3	0	2	9	16	15
Asia	1	3	9	0	5	4	1	6	1	2	14	14
Pan-tropical	**1**	**7**	**19**	**11**	**23**	**27**	**5**	**7**	**17**	**17**	**37**	**63**
% of each zone's SU	*3.7*	*25.9*	*70.4*	*18.0*	*37.7*	*44.3*	*17.2*	*24.1*	*58.7*	*14.5*	*31.6*	*53.9*
	29.6			*55.7*			***41.3***			***46.1***		

Levels of field knowledge:

Verif. = **Field verification**. Thorough reconnaissance of the study area, with satellite images, from the ground and from light aircraft.

Famil. = Good **familiarity** with the exact study area. The interpreter had already visited the study area in the recent past with the purpose of verifying image interpretations.

Refer. = Knowledge based only on **reference material**. Knowledge of the field conditions in the study area is based only on knowledge of similar zones and/or maps and reports describing its vegetation and land use

Table (3.4) 1 shows that field knowledge was not evenly distributed by geographical region and ecological zone. Among the African sampling units, out of 47, only six could be field verified and only seven were familiar to the interpreters.

The situation for Latin America and Asia was much better, where nine and two SUs, respectively, could be field verified and many interpreters were familiar with the sample locations since they are responsible, within their institutions, for the interpretation of satellite data for vegetation mapping. In synthesis, the interpretations were based on *good field knowledge* (verification or familiarity) in 62.5 percent of the cases for Latin America and 53.3 percent for Asia.

From an ecological perspective, it could be assumed that the interpretation tends to be more difficult in drier than in wetter conditions, as discussed under Section 4.4, making the field knowledge of the dry and moist zones a more valuable ingredient for reliable interpretation than in the wet zone. Following on from this assumption, more efforts have been put into verifying the sampling units of the moist and dry zones, with a resulting "verification intensity" almost five times higher than in the wet zone (18.0 and 17.2 percent versus 3.7). This is also reflected in the share of *good field knowledge* as the sum of verification and familiarity (last line of the table) where moist (55.7%) and dry (41.3%) well exceed the wet (29.6%), where such field knowledge is less important.

3.5 VALIDATION OF INTERPRETATION AND COMPILATION RESULTS

The results of the interpretation and compilation exercises conducted for each SU, produced through cooperation or contractual agreement, have been evaluated carefully and validated at Project Headquarters prior to any further analysis. This evaluation was carried out with the purpose of verifying that:

- the classification scheme was properly understood and applied,
- the interdependent interpretation procedure was properly applied and the results coherent,
- the data entry and compilation of results were carried out accurately and in accordance with standard procedures.

The first two phases of the evaluation/validation were conducted on the basis of the images and interpretation overlays. The focus of the evaluation was not the delineation of the classes, which is the prerogative of the interpreter, but rather its consistency: **interpretation consistency**, which means the coherent application of the interpretation key throughout the image (and images), and **classification consistency** according to the standard classification scheme, which makes the results of all SUs compatible.

The evaluation of the interdependent interpretation of historical and recent images was carried out by overlapping and comparing the two interpretation overlays. These two overlays had to be co-registered spatially, in spite of the relative distortion presented by the images, and the changes had to be clearly evident when comparing one image to the other.

In cases of poor classification or lack of consistency, the SU was re-analysed by the same interpreter after additional training, if this was feasible, or by a new interpreter.

The validation of data entry and compilation was carried out in two phases: (i) using LOTUS123® software to check the files for completeness and proper coding; and (ii) transforming the spreadsheet data into raster maps using IDRISI® in order to visualise the classes and check for data entry errors. The cross-classification of the two state maps (historical and recent), used to produce the change map, allowed one to visualise the location of all changes and compare these changes once more to the two images for a final check.

In the case of wrong or missing codes or errors in data entry, the corrections were made directly at Project Headquarters and then the analysis was finalised.

Chapter IV

Results and Findings

4.1 RESULTS AND ANALYSIS AT INDIVIDUAL SAMPLING UNIT LEVEL

In each Sampling Unit (SU), nine detailed land cover classes, including four forest classes, have been measured at two points in time. The time dimension refers to one historical satellite image acquisition close to the year 1980 and a recent one close to the year 1990. For each SU, the spatial location of different forest and land cover classes, and the changes that have occurred among those classes have been studied within this 185x185 km landscape. Interpretation and compilation procedures are described in Chapter II "Methodology".

With a size of some three million hectares, comparable to an entire district or province, one SU provides a wealth of location-specific information which can be useful in future studies that go beyond the sampling frame of this pan-tropical survey.

From the study of each SU two sets of data have been produced:

- **state assessment** results, based on the whole recent satellite image, giving the area statistics resulting from interpretation; and
- **change assessment** results, based on the area common to both the recent and the historical images, consisting of one area transition matrix (called change matrix) which reports the class-to-class changes observed.

While the state assessment consists of conventional area statistics, the change assessment, resulting in an area transition matrix or simply *change matrix*, is of particular interest in view of the rich information contained therein.

The change matrix in Table (4.1) 1, which shows the result of the interdependent interpretation of one of the 117 Sampling Units studied in the present survey, will serve as an example of change analysis based on matrix data. This Sampling Unit has been coded 4409 and is located in North East India, covering partly the states of Assam and Nagaland. The images used were Landsat Multi Spectral Scanner (MSS) and Thematic Mapper (TM), dated 6 December 1981 and 5 February 1988, respectively.

The results of the change analysis based on the change matrix above, and following the definitions discussed in section 2.2.1, are summarized in Table (4.1) 2. The complete analysis of changes for all land cover categories is presented in Annex 11.

Process of change

In addition to the calculated rates of change, the change matrix contains very interesting information on land use dynamics.

In Table (4.1) 1 the classes are ranked by decreasing biomass value, with the exception of the Plantation (Man-made Woody Vegetation) class, which appears last in view of its particular role. By placing the classes in this order, the values above the diagonal of the transition matrix (top-left to bottom-right) represent negative changes, viz, loss of biomass, while the values below the diagonal represent positive changes, viz, increase of biomass. The values along the diagonal represent the stable areas where no change has occurred.

Table (4.1) 1: Change matrix of Sampling Unit 4409 in North East India
Period covered: December 1981 - February 1988

	Interpretation classes of recent image (thousand hectares)									TOTAL historical image	
Interpretation classes of historical image	**Closed Forest**	**Open Forest**	**Long Fallow**	**Frag-mented Forest**	**Shrubs**	**Short Fallow**	**Other Land Cover**	**Water**	**Planta-tion**	**'000 ha**	
Closed Forest	1078.0	0.8	46.0	21.6	1.2		25.2		2.4	**1175.2**	***42.0***
Open Forest	0.8	40.8		0.4	1.6		1.6			**45.2**	***1.6***
Long Fallow	6.0		683.6	80.8	12.0		47.2		0.4	**830.0**	***29.7***
Fragmented Forest	6.8		18.4	80.8	0.4		7.6			**114.0**	***4.1***
Shrubs					30.4					**30.4**	***1.1***
Short Fallow											
Other Land Cover	1.2		8.8	0.8			532.8			**543.6**	***19.4***
Water								10.4		**10.4**	***0.4***
Plantation							0.8		46.8	**47.6**	***1.7***
TOTAL recent image '000 ha	**1092.8**	**41.6**	**756.8**	**184.4**	**45.6**	**0.0**	**615.2**	**10.4**	**49.6**	**2796.4**	
%	***39.1***	***1.5***	***27.1***	***6.6***	***1.6***	***0.0***	***22.0***	***0.4***	***1.8***		***100.0***

Table (4.1) 2: Summary of change assessment results for Sampling Unit 4409
Period covered: December 1981 - February 1988
The terms used are discussed in Section 2.2.1: "Definition of forest and forest area changes"

	Total '000 ha	Annual '000 ha	Simple annual % rate
Gross Deforestation	163.1	27.2	1.30
Net Deforestation	136.0	22.7	1.09
Net Degradation of Natural Forest	40.0	6.7	0.32

Balance between NATURAL FOREST and MAN-MADE WOODY VEGETATION

		Natural Forest (continuous and fragmented)	Man-made Woody Vegetation (1)	Total Natural + Man-made
Historical image (hist.)	'000 ha	2 088.4	47.6	2 136.0
Recent image (rec.)	'000 ha	1 952.7	49.6	2 002.3
Difference (hist.-rec.)	'000 ha	-136.0	2.0	-134.0
Simple annual rate	'000 ha	-22.7	0.3	-22.4
Simple annual rate	%	-1.09	0.70	-1.05
Compound annual rate	%	-1.11	0.69	-1.07

(1) **Man-made Woody Vegetation** includes both forest plantations and agricultural plantations

Table (4.1) 3 and, in particular, Figure (4.1) 1, present more clearly the information contained within the change matrix.

The matrix in Table (4.1) 3 gives the relative values of class-to-class change as percentages of the total area that has undergone change (calculated by adding all the values above and below the diagonal, equal to 292 800 hectares). The row totals in the last two columns give the area changed by class of *origin* and the relative percentage of the total change. The column totals in the lower rows give the area and percentage by class of *destination*.

Table (4.1) 3: Analysis of changes in Sampling Unit 4409
(Percentages of total change)

	Interpretation classes of recent image (thousand hectares)									Total Change by class of origin	
Interpretation classes of historical image	Closed Forest	Open Forest	Long Fallow	Fragmented Forest	Shrubs	Short Fallow	Other Land Cover	Water	Plantation	'000 ha	%
Closed Forest	-	0.3	15.7	7.4	0.4		8.6		0.8	**97.2**	***33.2***
Open Forest	0.3	-		0.1	0.5		0.5			**4.4**	***1.5***
Long Fallow	2.0		-	27.6	4.1		16.1		0.1	**146.4**	***50.0***
Fragmented Forest	2.3		6.3	-	0.1		2.6			**33.2**	***11.3***
Shrubs					-						
Short Fallow						-					
Other Land Cover	0.4		3.0	0.3			-			**10.8**	***3.7***
Water								-			
Plantation							0.3		-	**0.8**	***0.3***
Total change by class of destination '000	**14.8**	**0.8**	**73.2**	**103.6**	**15.2**	**0.0**	**82.4**	**0.0**	**2.8**	**292.8**	
%	***5.1***	***0.3***	***25.0***	***35.4***	***5.2***	***0.0***	***28.1***	***0.0***	***1.0***		***100.0***

From Table (4.1) 3 it appears that:

- The most common classes of **origin** where changes have occurred are ***Long Fallow*** (forest affected by shifting cultivation), with 50 percent of the total changed area, followed by ***Closed Forest***, with 33.2 percent.
- The most common **destinations** of the changes were: ***Fragmented Forest*** (35.4 percent), ***Other Land Cover*** or permanent agriculture (28.1 percent) and ***Long Fallow*** (25 percent).
- The most important class-to-class transition is ***Long Fallow ⇒ Fragmented Forest*** which indicates those areas where shifting cultivation has stabilized and intensified, probably on the most fertile valleys and gentle slopes, resulting in a mosaic of secondary forest and cultivated fields.
- Other important transitions are ***Closed Forest ⇒ Long Fallow*** and ***Long Fallow ⇒ Other Land Cover*** (15.7 percent and 16.1 percent, respectively). Although these two transitions are simultaneous and not subsequent, they provide a reliable indication of the direction of change in the study area.

However, these percentages alone do not give the full impact of the observed land cover changes in terms of environmental degradation, related loss of biomass, and the overall detrimental effects of forest depletion. The magnitude of the changes can be put into better perspective when associated with estimates of biomass (see Section 2.8 "Biomass change analysis"). A nominal biomass value for each class permits the estimation of the biomass changes related to each class transition.

The woody biomass flux diagram in Figure (4.1) 1, which combines the values shown in Table (4.1) 1 with the estimated biomass values, is structured as follows:

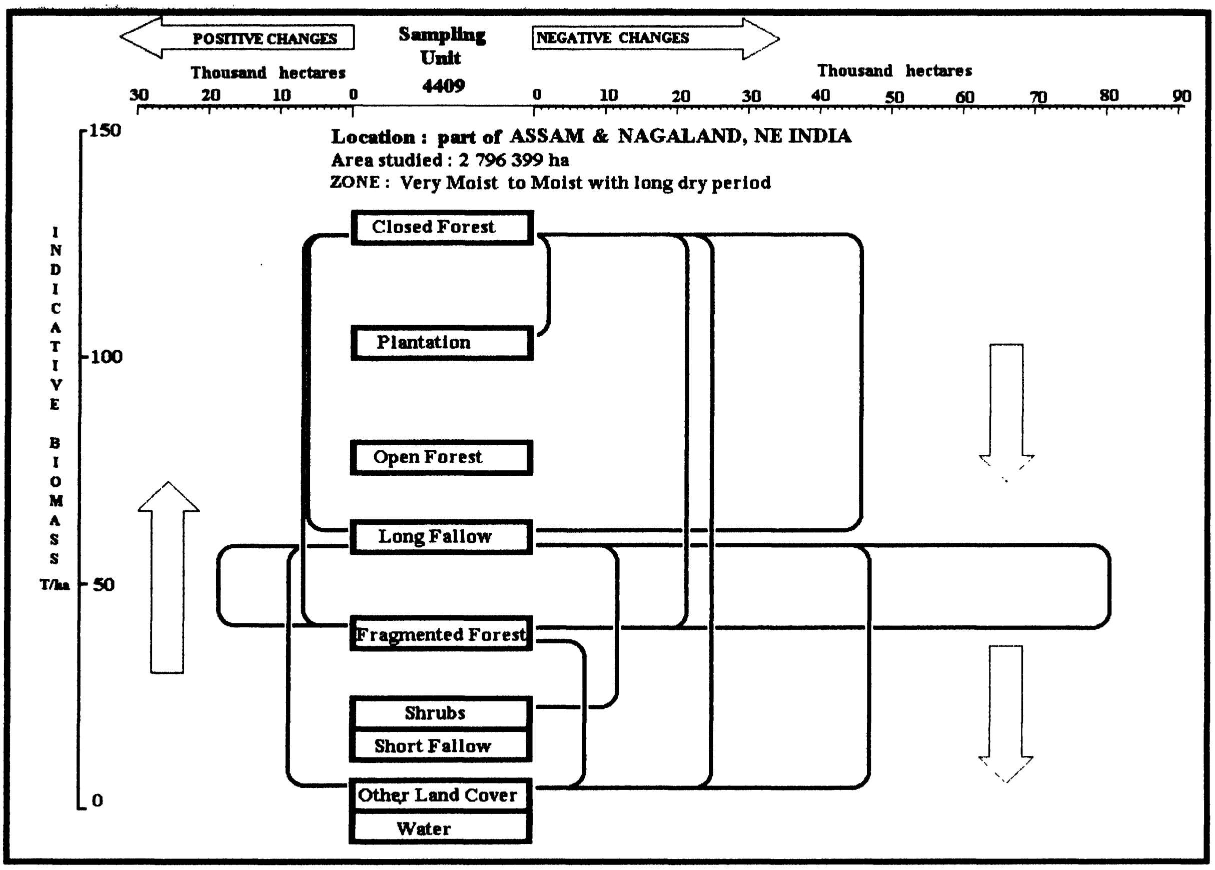
- The Y axis, with its biomass values, shows the order of the classes by their estimated biomass per hectare.
- The X axis reports the areas of class-to-class transition, divided into *positive* and *negative* changes. The left side of the graph represents the lower-left part of the matrix, showing the positive class transitions (the arrow pointing upward indicates an increment in biomass), while the right side of the graph represents the upper-right part of the matrix, showing the negative class transitions (the arrow pointing downward indicates a loss of biomass).

Each transition is defined by the area value on the X axis and by the biomass value determined as the difference between the biomass values of the class of destination and the class of origin. Each transition is therefore represented by a rectangle, the area of which quantifies the total biomass change implicit in a class-to-class transition.

By including the biomass perspective, one is able to visualise and better understand the change processes, and even assess their environmental impact through the release (or sequestration) of woody biomass related carbon.

However, the biomass values allocated to each class are only indicative since no direct biomass measurements have been taken. The values used here have been inferred, for each land cover class, from biomass estimates produced by applying regression equations for estimating total aboveground biomass (Brown and Iverson, 1992) to stand tables from the forest inventory of the state of Nagaland (FSI, 1988).

Figure (4.1) 1: Woody biomass flux diagram of SU 4409



The woody biomass flux diagram shows, inter alia, that:

- Negative changes in biomass and forest area are far more prevalent than positive ones.
- There is a positive-negative symmetry, although strongly unbalanced, in the transitions among the classes ***Closed Forest*, *Long Fallow*, *Fragmented Forest*** and ***Other Land Cover*** (*symmetry* represented by transitions of opposed signs involving the same classes; *unbalanced* due to strong predominance of negative transitions). These symmetric changes represent clearly the cyclic land use character of the areas affected by shifting cultivation practices. However, the predominance of negative changes shows conclusively that the cycle is not stable, but rather moving with increasing speed toward degradation.
- The ***Long Fallow* ⇒ *Fragmented Forest*** transition is the most frequent one but it involves a comparatively small change in biomass. From the point of view of biomass economy (the area of the rectangle defining each transition), the ***Closed Forest* ⇒ *Other Land Cover*** transition is the most important one, followed by ***Closed Forest* ⇒ *Long Fallow*** and by ***Long Fallow* ⇒ *Other Land Cover***.

In addition to the results presented so far, and in order to study the state and change of forest resources for the period 1980-1990, the results of each SU have been analysed, as described in Section 3.4, and the following standard outputs were produced:

(i) a transition probability matrix for the period 1980-1990;
(ii) a derived area matrix for the same period; and
(iii) an adjustment of the forest area of the recent image to the year 1990.

The standardized SU results have been used as inputs for carrying out the statistical analysis of forest cover, deforestation rate, and the process of change at various reporting levels; these results have been reported in the following Sections.

Spatial output

For each SU two interpretation were produced, one for the recent and one for the historical image, showing class delineation. Both overlays were co-registered to the scale and projection of the recent image (scale 1: 250 000).

Digital raster maps were produced for all interpretation overlays using the spreadsheet files created during the compilation phase with, inter alia, the immediate objective of detecting possible data entry errors (see Sections 2.4 and 2.7 for details on the compilation system and raster map production). For each SU the following set of maps was produced using IDRISI® software:

- **State maps** for recent and historical images with ten land cover classes (main classes only).
- **Change maps**, produced through the cross-classification of recent and historical maps, with 15 classes of change (see Table (2.7) 1 for a detailed description of the legend of land cover changes).

In addition to their immediate use in validating the statistics produced for each SU, and in spite of their relatively coarse resolution (pixels of 400 hectares), these maps represent a very important output in the context of a multi-layer global Geographic Information System.

As example of the raster maps produced on the basis of the data generated for each SU, Figure (4.1) 2 shows the maps generated for SU 4409.

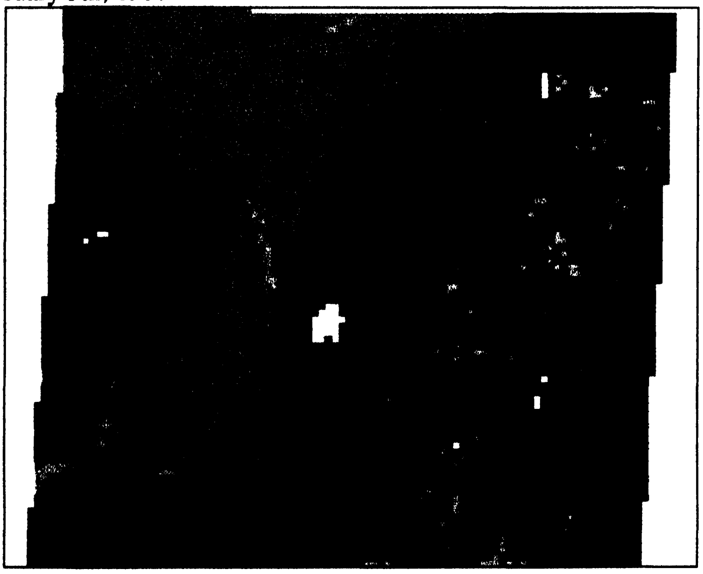
A second set of digital maps is presently being produced by digitizing the original interpretation overlays to full resolution and geographic correction. This full resolution mapping activity, which involves considerable additional costs and time, is at present in progress of implementation.

In view of the rather large area covered, the set of maps produced for each SU represents a document with its own inherent value, showing, in spatial and statistical form, the dynamics that have taken place in that particular location during a specific time period. The potential use of these results goes well beyond the present statistical survey, or the proposed continuous monitoring approach. Its global consistency, spatial and thematic resolution provide a sound basis on which the spatial and statistical modelling of deforestation and forest degradation can be carried out.

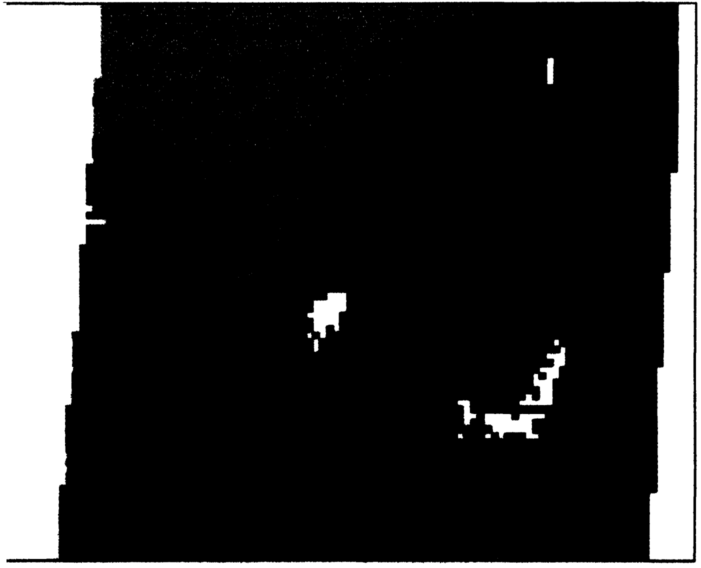
Figure (4.1) 2 : Raster maps of Sampling Unit 4409

December 6th, 1981

February 5th, 1988



Land Cover Changes: December 1981 - February 1988



LEGENDS

LAND COVER CLASSES

Closed Forest	■
Open forest	■
Long Fallow	■
Fragmented Forest	■
Short Fallow	■
Shrubs	▨
Other Land Cover	▨
Water	■
Plantations	
Non Visible	□

LAND COVER CHANGES

Deforestation	■
Fragmentation	■
Partial Deforestation	■
Degradation	■
Decrease of Biomass	▨
Forest ↔ Plantations	
Stable Forest	
Stable Fragmented Forest	
Stable Non-forest	
Increase of Biomass	
Amelioration	
Partial Afforestation	
Afforestation (natural)	
Non Visible	

4.2 1980-1990 CHANGE PROCESSES AT GLOBAL, REGIONAL AND ECOLOGICAL LEVELS

The most interesting result of the survey is the set of change matrices produced, one for each Sampling Unit (SU), to describe in detail the class-to-class transitions that occurred during the period between the dates of acquisition of the satellite images used. Before being used for regional and global synthesis the change matrices were **standardized** for the 10-year period 1980-1990. This adjustment was effected through the mathematical analysis of the annual and periodic class transition probability of each matrix (see Section 2.5). The resulting standard matrices have then been **post-stratified** according to ecological characters and aggregated according to classical statistical methods for sample survey that take into account the unequal probability of inclusion.

Mean transition matrices were produced at pan-tropical level, for three tropical regions (Africa, Latin America and Asia) and for three broad ecological zones (wet and very moist, moist and dry). The results discussed below derive from the expansion of the mean transition matrices, to the total land area of the corresponding sampling frame section from which the SUs were selected. This excluded satellite scenes "non-forested" or with less than one million hectares of land (see Section 2.1.1). The area surveyed, and represented by the results given below, is given in Annex 4, for the geographic regions, and in Table 1 of Section 4.2.3, for the ecological zones. As a consequence, the estimated forest cover and deforestation rates discussed here cannot be directly compared to other estimates referring to total and regional tropical countries' land area[1].

4.2.1 Global level results (pan-tropical overview)

Transition matrix

Table (4.2.1) 1 shows the global area matrix based on the survey data, which gives the estimated class-to-class transitions that occurred in the total land area surveyed for the period 1980-1990.

Table (4.2.1) 1: Pan-tropical area transition matrix for the period 1980-1990[2]

Land Cover Classes in 1980	Land Cover Classes in 1990 (Million hectares)									TOTAL 1980	
	Closed Forest	Open Forest	Long Fallow	Fragmented Forest	Shrubs	Short Fallow	Other Land Cover	Water	Plantations	Million ha	%
Closed Forest	**1275.91**	8.97	9.27	9.17	2.53	21.57	34.79	1.78	3.95	**1367.96**	***44.6***
Open Forest	0.86	**283.31**	1.30	5.18	1.46	2.40	10.18	0.05	0.21	**304.94**	***9.9***
Long Fallow	1.10	0.26	**48.61**	1.08	0.79	2.35	2.27	0.05	0.01	**56.54**	***1.8***
Fragment. Forest	0.58	0.63	0.63	**159.33**	0.45	1.41	11.40	0.25	0.39	**175.06**	***5.7***
Shrubs	0.15	0.20	0.26	0.14	**152.6**	0.34	19.17	0.19	0.15	**173.30**	***5.6***
Short Fallow	0.56	0.29	0.46	0.39	0.16	**119.79**	7.30	0.19	0.17	**129.31**	***4.2***
Other Land Cov.	0.71	0.70	0.26	1.35	1.94	2.03	**834.23**	1.58	0.44	**843.26**	***27.5***
Water	0.14	0.02	0.01	0.05	0.01	0.07	1.46	**stable**	0.02	**1.78**	***0.1***
Plantation	0.05	0.03	0.00	0.00	0.00	0.01	0.11	0.00	**15.68**	**15.88**	***0.5***
TOTAL 1990 Million ha	**1280.06**	**294.41**	**60.81**	**176.69**	**160.0**	**149.97**	**920.91**	**4.09**	**21.03**	**3068.01**	
%	***41.7***	***9.6***	***2.0***	***5.8***	***5.2***	***4.9***	***30.0***	***0.1***	***0.7***		***100.0***

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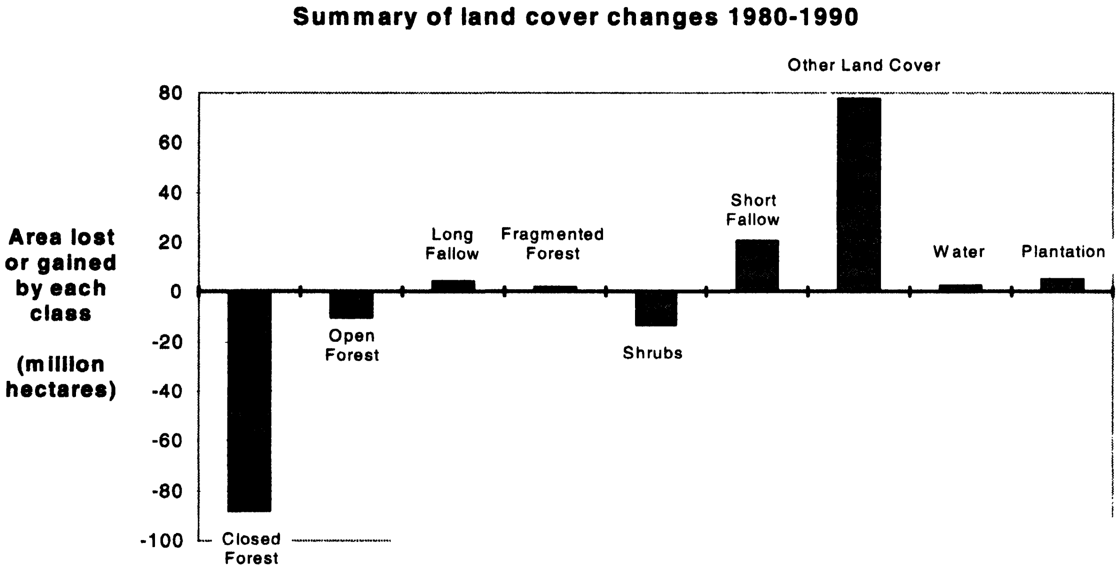
[1] For a specific comparison with Phase I estimates for tropical countries, published in Forestry Papers 112 and 124 [FAO 1993 and 1995], see Section 5.1 "Relation between the Remote Sensing Survey and FORIS (FAO Forest Resources Information System) databases".

[2] Results are based on the **visible common area** between recent and historical satellite images. Stable water (ocean, sea, lakes and rivers) has been excluded from the analysis of changes.

A first set of data can be derived by comparing the row totals, which reflect the situation in 1980, and the column totals, which reflect the situation in 1990. Figure (4.2.1) 1 illustrates the result of this comparison, showing the total area lost or gained by each land cover class during the ten-year period. These values represent the net changes, viz., the algebraic sum of all gain and loss for each class.

Figure (4.2.1) 1: Pan-tropical summary of net changes during 1980-1990 by land cover class



A more complex description of the changes that occurred during the decade under study can be derived from the inner part of the transition matrix which is very rich in information but somewhat difficult to interpret.

As mentioned above, row totals give the class areas in 1980 while the column totals give the class areas in 1990. The shaded values along the diagonal of the matrix represent the class areas that remained unchanged.

To determine the changes observed in any single class, e.g., ***closed forest***, one first needs to read the total area of that class in 1980,.namely, 1 367.96 million hectares, and then read along the row inside the matrix: 1 275.91 remained unchanged, 8.97 changed into *open forest*, 9.27 changed into *long fallow*, and so on. The most important change that the *closed forest* class underwent was 34.79 million hectares that changed into *other land cover*.

In order to complete the analysis concerning the class *closed forest* one should also consider what other classes have become closed forest; this is done by reading down the closed forest column: of a total of 1 280.06 million hectares in 1990 (column total), 1 275.91 million hectares were already *closed forest* in 1980, 0.86 were *open forest* in 1980, 1.10 were *long fallow*, and so on. The largest, but still comparatively modest, transition to *closed forest* derived from the *long fallow* class; this transition refers to areas where the practice of long fallow shifting cultivation was abandoned, with consequent regeneration of the forest.

The results[3] of the systematic analysis of class transition are summarized in Table (4.2.1) 2. A complete analysis of changes for all Land Cover Categories is presented in Annex 12.

The forest area estimates given below refer to the **F3** definition of forest, discussed in Section 2.2.1, which includes the following classes:

Closed Forest
Open Forest
Fragmented Forest
Long Fallow

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[3] The results shown in this Section and in Annexes 12 to 15 and 17 to 20 are based on the change matrices and therefore on the visible common area between recent and historical images. Thus, they slightly differ from the statistical results at pan-tropical and regional levels presented in Section 4.3 "Statistical results by definition of forest (mean estimates and associated error of forest cover and deforestation rates)", which are based on the full area of recent images.

Table (4.2.1) 2: Summary of forest cover changes in the period 1980 - 1990
The terms used are discussed in Section 2.2.1: "Definition of forest and forest area changes"

	Total (million ha)	Annual (million ha)	Simple annual (% rate)
Gross Deforestation	99.33	9.93	0.56
Net Deforestation	93.62	9.36	0.52
Net Degradation of Natural Forest	17.33	1.73	0.10

Balance between NATURAL FOREST and MAN-MADE WOODY VEGETATION

		Natural forest (continuous and fragmented)	Man-made woody vegetation (1)	Total natural + man-made
Area at year 1980	million ha	1 787.2	15.88	1803.1
Area at year 1990	million ha	1 693.6	21.03	1714.6
Difference 1980-1990	million ha	-93.62	5.16	-88.46
Simple annual rate	million ha	-9.36	0.52	-8.85
Simple annual rate	%	-0.52	3.25	-0.49
Compound annual rate	%	-0.54	2.85	-0.50

(1) Man-made woody vegetation includes both forest plantations and agricultural plantations

From the aggregated area matrix one can derive the weighted mean transition probability matrix, as shown in Table (4.2.1) 3, which indicates the probability of any particular class changing into another one (or remaining the same) during the period 1980-1990.

Table (4.2.1) 3: Pan-tropical transition probability matrix
(Estimated mean probability of class-to-class transition in the period 1980-1990)

	Classes in 1990									
Classes in 1980	**Closed Forest**	**Open Forest**	**Long Fallow**	**Fragmented Forest**	**Shrubs**	**Short Fallow**	**Other Land Cover**	**Water**	**Plantations**	**TOTAL**
Closed Forest	.933	.007	.007	.007	.002	.016	.025	.001	.003	1
Open Forest	.003	.929	.004	.017	.005	.008	.033	.000	.001	1
Long Fallow	.019	.005	.860	.019	.014	.042	.040	.001	.000	1
Fragmented Forest	.003	.004	.004	.910	.003	.008	.065	.001	.002	1
Shrubs	.001	.001	.002	.001	.881	.002	.111	.001	.001	1
Short Fallow	.004	.002	.004	.003	.001	.926	.056	.001	.001	1
Other Land Cover	.001	.001	.000	.002	.002	.002	.989	.002	.001	1
Water[4]	.079	.013	.003	.028	.008	.038	.820		.012	1
Plantation	.003	.002	.000	.000	.000	.001	.007	.000	.988	1

In order to focus on changes only, the matrix in Table (4.2.1) 4, below, gives the observed transitions as percentages of the total area that underwent change (the sum of all values above and below the diagonal; equal to 178.46 million hectares). The row totals give both the area and the percentage of total change by class of *origin*. The column totals give the area and percentage by class of *destination*.

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[4] Refers only to the area of *water* that has changed. Stable water (ocean, sea, lakes and rivers) has been excluded from the analysis of changes.

Table (4.2.1) 4: Analysis of change
(Values within the matrix are percentages of the total area where change occurred during the period 1980-1990)

	Classes in 1990									Total Change by class of origin	
Classes in 1980	**Closed Forest**	**Open Forest**	**Long Fallow**	**Frag-mented Forest**	**Shrubs**	**Short Fallow**	**Other Land Cover**	**Water**	**Planta-tions**	**Million ha**	**%**
Closed Forest	-	5.0	5.2	5.1	1.4	12.1	19.5	1.0	2.2	**92.04**	***51.6***
Open Forest	0.5	-	0.7	2.9	0.8	1.3	5.7	0.0	0.1	**21.63**	***12.1***
Long Fallow	0.6	0.1	-	0.6	0.4	1.3	1.3	0.0	0.0	**7.92**	***4.4***
Fragmented Forest	0.3	0.4	0.4	-	0.3	0.8	6.4	0.1	0.2	**15.73**	***8.8***
Shrubs	0.1	0.1	0.1	0.1	-	0.2	10.7	0.1	0.1	**20.60**	***11.5***
Short Fallow	0.3	0.2	0.3	0.2	0.1	-	4.1	0.1	0.1	**0.95**	***5.3***
Other Land Cover	0.4	0.4	0.1	0.8	1.1	1.1	-	0.9	0.2	**9.02**	***5.1***
Water	0.1	0.0	0.0	0.0	0.0	0.0	0.8	-	0.0	**1.78**	***1.0***
Plantations	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	-	**0.19**	***0.1***
Total change by class of destination M[1]ha	**4.14**	**11.10**	**12.19**	**17.36**	**7.34**	**30.18**	**86.67**	**4.09**	**5.35**	**178.46**	
Total change by class of destination %	***2.3***	***6.2***	***6.8***	***9.7***	***4.1***	***16.9***	***48.6***	***2.3***	***3.0***		***100.0***

[1] Area in million hectares

From this table it would appear that:

- The most common class of **origin** of the changes is ***closed forest*** with 51.6 percent of the total area having undergone change, followed by ***open forest*** with 12.1 percent and ***shrubs*** with 11.5 percent.

- The most common class of **destination** of the changes is ***Other Land Cover*** (mainly through a shift to cattle ranching and permanent agriculture) with 48.6 percent of all changes, followed by ***short fallow*** (subsistence agriculture) with 16.9 percent and ***fragmented forest*** with 9.7 percent.

- The most important class-to-class transitions are: ***closed forest ⇒ other land cover*** (19.5 percent), followed by ***closed forest ⇒ short fallow*** (12.1 percent) and ***shrubs ⇒ other land cover*** (10.7 percent).

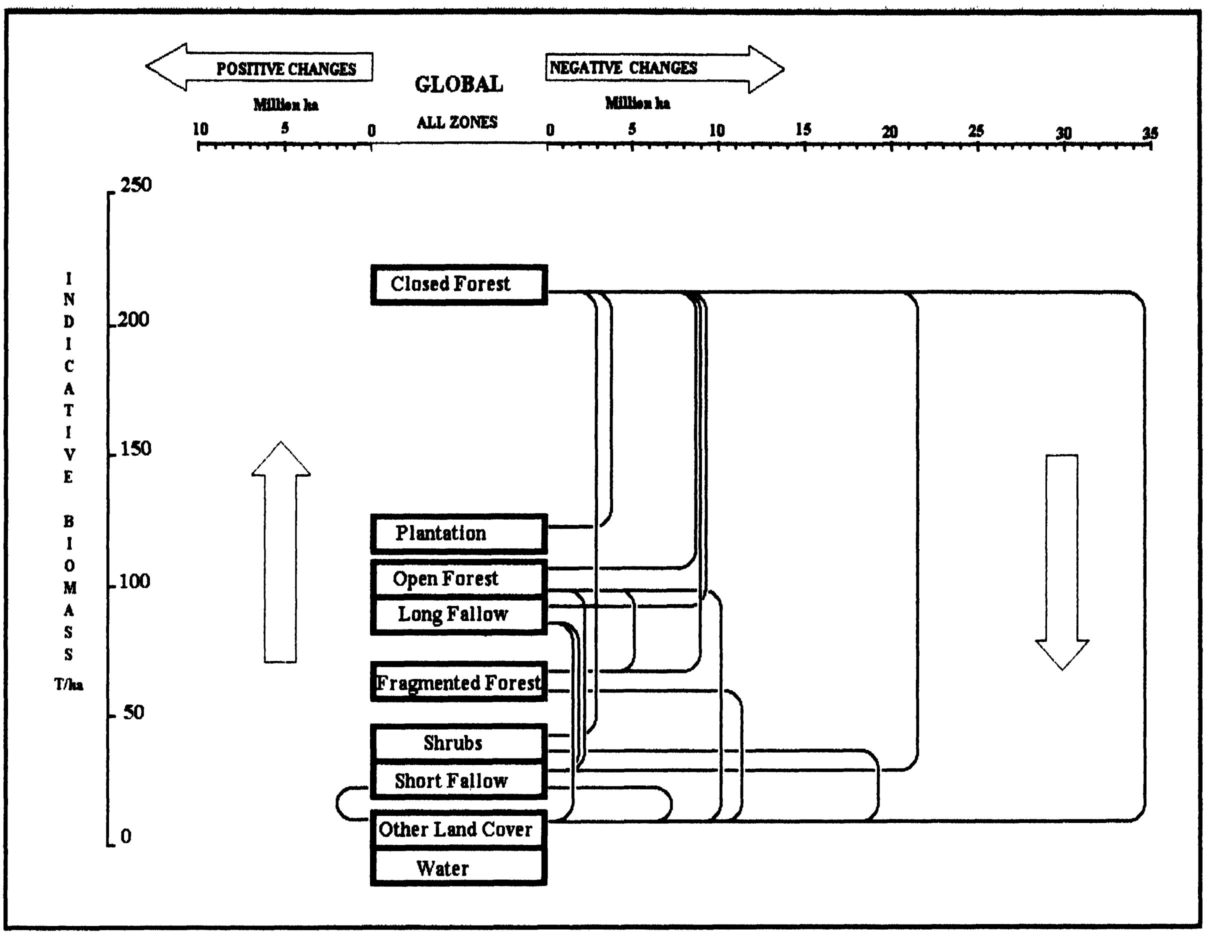
The values reported in the tables above do not indicate fully the environmental impact of the observed land cover changes. The full magnitude of the changes can be put into better perspective when associated with estimates of biomass. An estimated mean biomass value for each class permits one to visualize and, to some extent, estimate the biomass changes related to each class transition (see Section 2.8 "Biomass Change Analysis").

Similar to the analysis of SU 4409, described in Chapter 4.1, the areas of transition given in Table (4.2.1) 1 are illustrated graphically in Figure (4.2.1) 2, using indicative biomass values to estimate the "gradient" of class-to-class transitions.

As explained in greater detail in section 4.1, the X and Y axis represent, respectively, the area of change and the (indicative) woody biomass of the classes used. The X axis is in turn divided to represent positive and negative changes on the basis of increases or decreases in biomass implicit in the transitions. Each change is represented by a rectangle, the area of which quantifies the total biomass change implicit in any class-to-class transition.

The biomass flux diagram developed in this study is an essential tool for understanding the types of change and, provided that biomass values are reliable, in quantifying their environmental impact in terms of carbon release/sequestration.

Figure (4.2.1) 2 : Pan-tropical woody biomass flux diagram



Note: Only class transitions involving more than 1.5 million hectares are shown in the diagram.

Figure (4.2.1) 2 shows clearly the complexity of the dynamics observed. Some remarks on the data gathered are mentioned below:

- negative changes are far more prevalent than the positive ones;
- almost all types of negative change are represented;
- the two largest area transitions, viz., ***closed forest ⇒ other land cover*** and ***closed forest ⇒ short fallow***, also imply the largest amount of biomass loss;
- for all other transitions, however, the biomass loss, that corresponds to the area of the rectangle indicating each transition, depends more on the biomass gradient than on the area of change; for example, in the third largest area transition (***shrubs ⇒ other land cover***) the biomass loss has been much less than in other transitions involving less area; and
- most of the new ***plantation*** areas (both agricultural and forestry) have been created on previous ***closed forest*** area, therefore implying, if the average biomass values are accurate, a loss of biomass.

The pan-tropical flux diagram reflects the summary of land use dynamics of a wide variety of socio-economic conditions and ecological environments. As a consequence, it shows well the overall result of all these local dynamics but cannot represent their contribution to the global trend nor describe their characteristic change processes. These local aspects, which are essential for understanding the cause-effect mechanisms threatening the resources, can be seen more clearly in the conclusive results presented at regional and ecological levels.

4.2.2 Regional level results

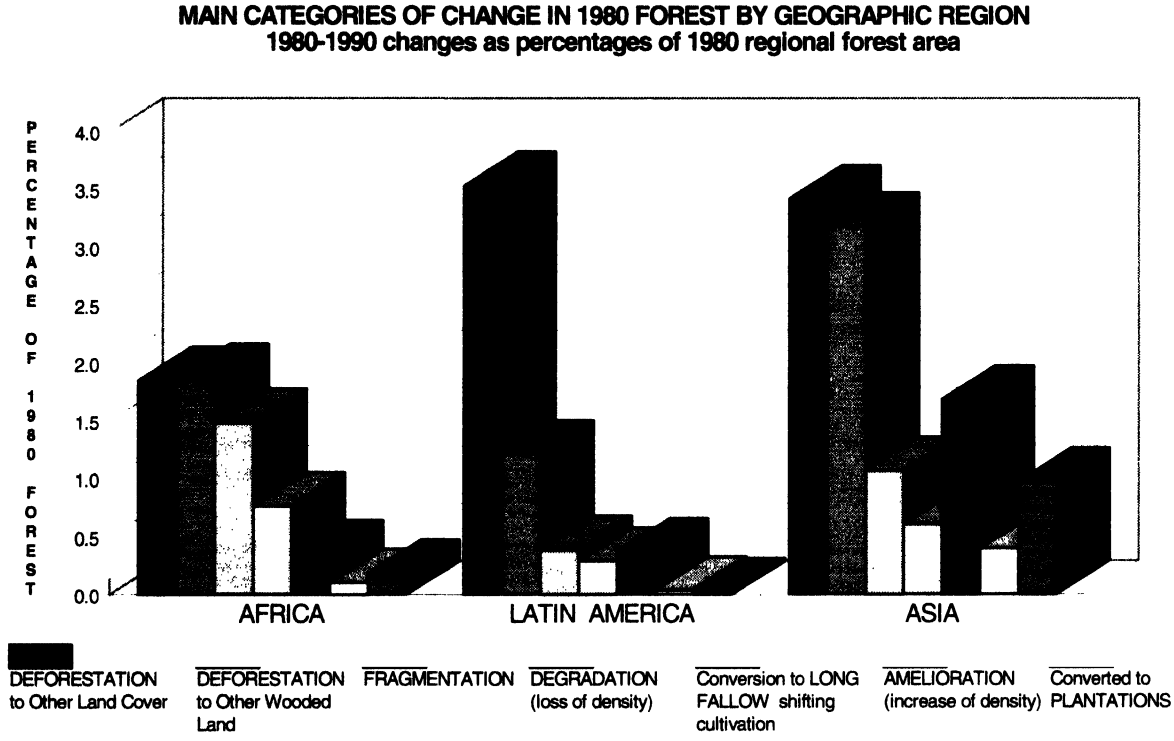
Regional characters in forest area change

The pan-tropical change matrix and the flux diagram of woody biomass, shown in the preceding pages, summarize the land use dynamics of a wide variety of socio-economic and ecological environments. In order to evaluate the influence of these various conditions on change processes it would be useful to subdivide the pan-tropical data set into meaningful strata with more homogeneous characters.

The influence of socio-economic factors on the change processes appears to be clearly evident when the results of the survey are analyzed at regional level. At that level of analysis one can differentiate between typical change processes and the cause-effect relationship can be better understood. Change matrices and flux diagrams for the three tropical regions, viz., Africa, Latin America and Asia, are presented in Annexes 13, 14 and 15, respectively.

The graph in Figure (4.2.2) 1, which summarizes the results by main categories of change, allows for the comparison of the regional characteristics in forest cover change.

Figure (4.2.2) 1: Main categories of forest cover change by geographic region

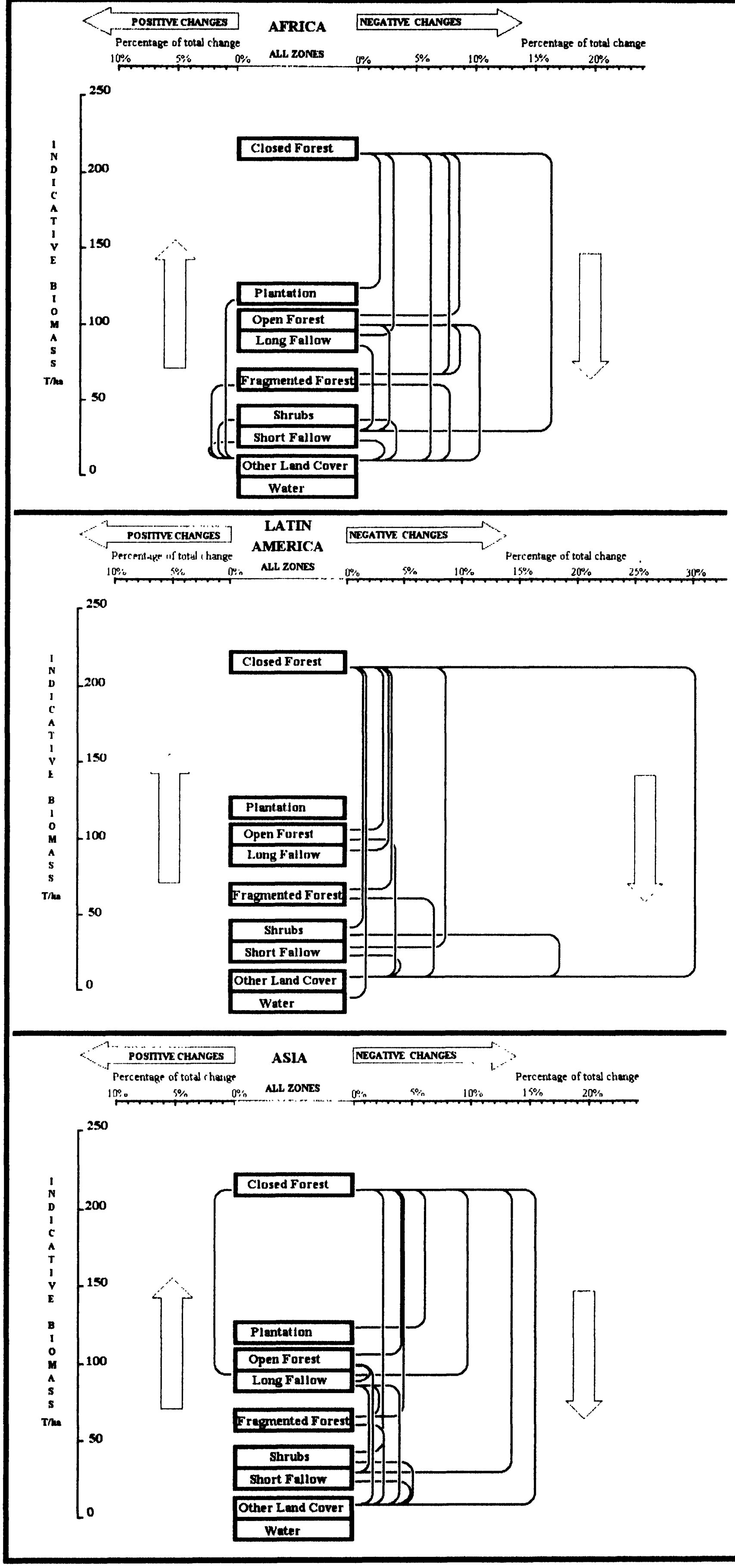


The different patterns of forest area change indicate that there are differences among regions in the socio-economic processes that cause change.

In Africa the **deforestation to other land cover** (mainly permanent agriculture) has been much less important than in the other regions and has been accompanied by a comparatively large degree of **deforestation to other wooded land** (shrubs and short fallow agriculture), **fragmentation** and **degradation**. The process of change in Africa appears to be distinguished by phases of progressive degradation, characterized by a variety of relatively small changes, both in area and in biomass. The main thrust behind this process has been rural population pressure for land (subsistence farming, pastures) and wood (fuelwood, construction material).

In Latin America the change process appears to be quite different, with **deforestation to other land cover** (permanent agriculture, pastures and water reservoirs) being by far the most important change while the other types of change are almost negligible. This has been mainly the effect of centrally planned operations of comparatively large scale (resettlement and forest exploitation/conversion). This process was

Figure (4.2.2) 2: **Regional biomass flux diagrams**



The effects of **rural population pressure** are very clear in **Africa** where the single most dominant tran-sition has been ***closed forest ⇒ short fallow*** (small-scale subsistence farming) and where many transitions have been represented with similar frequency; the sequences ***closed forest ⇒ open forest ⇒ fragmented forest ⇒ other land cover*** are typical and they represent clearly the various progressive stages of forest depletion.

In **Asia** this type of pressure is mainly represented by the sequences ***closed forest ⇒ long fallow ⇒ other land cover*** and ***closed forest ⇒ short fallow ⇒ other land cover***, reflecting the expansion and intensification of shifting cultivation (classes Long Fallow and Short Fallow) in the hills of South East Asia. Abandoned shifting cultivation areas are represented by the positive transition ***long fallow ⇒ closed forest.*** The difference between the forest area going into long fallow and the area of long fallow reverting to forest shows how unbalanced this originally sound practice has become.

In **Latin America** this type of change was less common but still visible in the transition ***closed forest ⇒ short fallow***, largely the effect of small-scale farming in Amazonia and/or Yucatan.

The effects of **centrally planned operations** are evident in Latin America and in Asia but to a much lesser degree in Africa. The typical transitions have been ***closed forest ⇒ other land cover*** or, relevant in Asia only, ***closed forest ⇒ plantation***. Typical land uses related to these processes were: large areas of deforestation owing mainly to cattle ranching in the Brazilian Amazon, large resettlement and plantation programmes in South East Asia and, to a lesser degree, in West Africa.

characterized by considerable changes both in area and in biomass. These changes were usually driven by financial investment and heavy mechanization.

In Asia both types of process seem to be represented, resulting in both significant **deforestation** and **degradation.** The **deforestation to other land cover** shows the effects of (i) large resettlement programmes involving forest exploitation/conversion (particularly in Indonesia and Malaysia); (ii) expansion of subsistence agriculture (short fallow shifting cultivation) that border forests along roads and existing crop land; and (iii) intensification of permanent agriculture on traditional shifting cultivation areas (South and South East continental Asia). The process of forest **degradation** was represented mainly by the expansion of forest affected by shifting cultivation (long fallow shifting cultivation), that encroached on previously dense or undisturbed forest. In this region a considerable area of forest has been converted to plantations, although primarily of the agricultural type.

The different processes of change are visible in greater detail in the regional biomass flux diagrams in Figure (4.2.2) 2. which show the frequency of all class-to-class transitions in relation to estimated biomass values. In order to focus on the most frequent and reliable class transitions and to improve the legibility of these diagrams, only the transitions accounting for more than two percent of the respective regional change are shown.

These diagrams, referring to percentages of each region's total change, allow for a comparison of the regional change processes, irrespective of the area that actually underwent change (see Annexes 13, 14 and 15 for more quantitative results).

Although all transitions have been simultaneous and not sequential (all have been based on the same two points in time), there are certain combinations of transition that imply a sequential character. On this basis the co-existence of changes such as *closed forest ⇒ long fallow* and *long fallow ⇒ other land cover* has been described here as a ***sequence*** of progressive degradation and the co-existence of changes of opposite sign such as *closed forest ⇒ long fallow* and *long fallow ⇒ closed forest* has been described as a ***cycle***.

Comparing the three regional biomass flux diagrams, shown in Figure (4.2.2) 2, the nature of the regional change processes is visible and very distinct.

4.2.3 Ecological level results

The forests of the tropical regions include a wide variety of formations, ranging from open tree savanna to multi-storey rainforest, which are indicators of complex and much varied ecosystems. Each forest ecosystem has distinctive characters in terms of, for instance, biodiversity and wildlife habitat, human habitat, environmental fragility and carbon density, etc. Similar changes in area in two distinct ecosystems can have quite different environmental implications. We need answers to questions as:

How are the diverse tropical ecosystems changing?

Are they undergoing the same processes and change rates?

The data presently available do not allow for detailed ecosystem level analyses; however, by stratifying the data available according to ecological parameters, good indications of the main trends affecting broad ecological zones can be obtained. Sampling unit results were therefore post-stratified and aggregated by ecological zone. The ecological parameters used were derived from of the Eco-floristic Zone Map of the Tropical Regions (FAO, 1988) which refers to Holdridge Life Zones (1959). The final ecological zones used here (see Figure (4.2.3) 1) represent a simplification of the original classifications and have been defined on the basis of rainfall parameters only. The population parameters of the ecological stratification are given in Table (4.2.3) 1 and the ecological zones have been defined as follows:

Z1 - Wet and Very Moist	(rainfall > 2000 mm)
Z2 - Moist (with short and long dry season)	(rainfall 1000-2000 mm)
Z3 - Sub-Dry to Very Dry	(rainfall 200-1000 mm)

Table (4.2.3) 1: Ecological stratification (Population parameters)

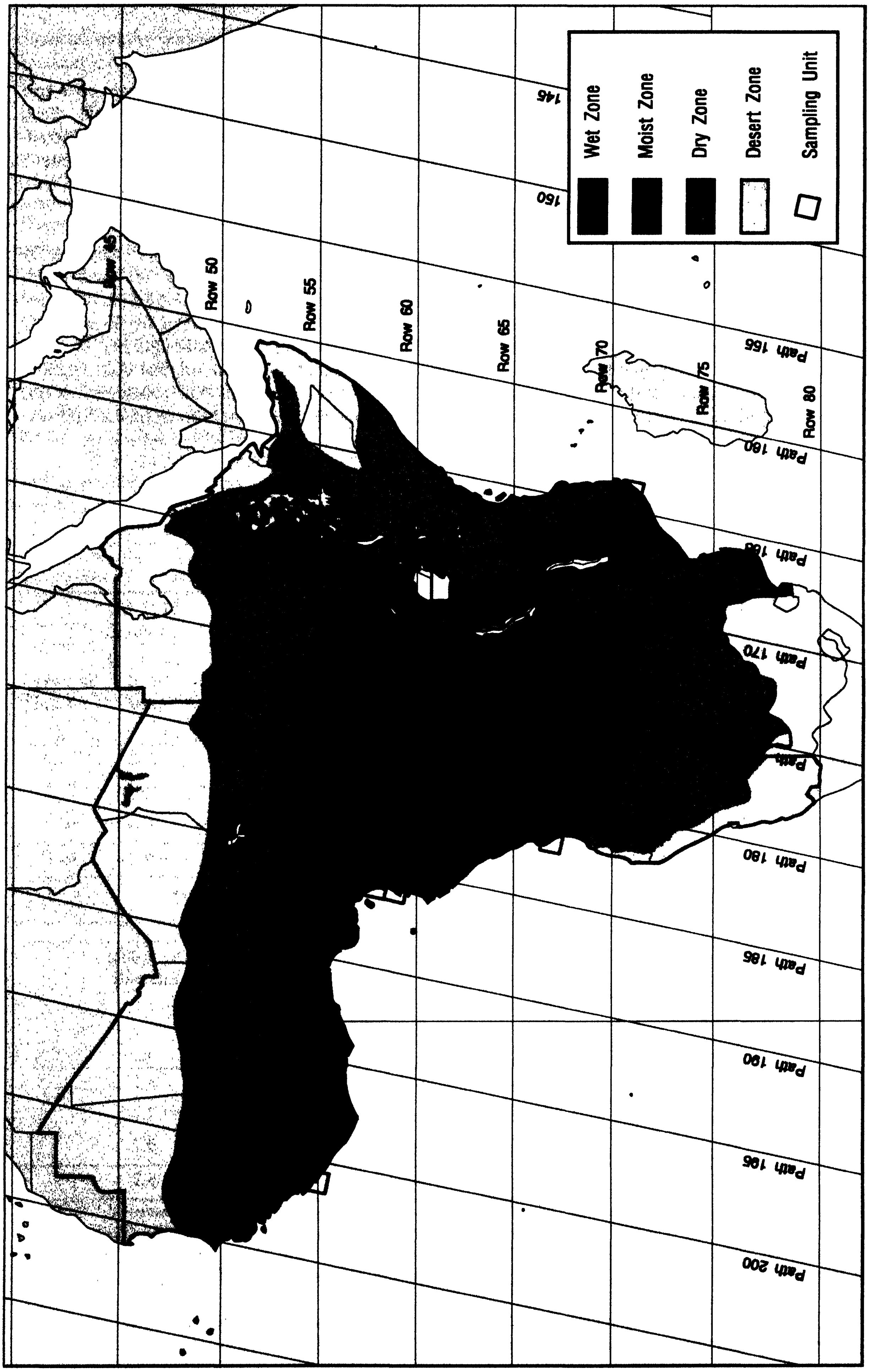
	Zone 1- WET		**Zone 2 - MOIST**		**Zone 3 - DRY**		**TOTAL (all zones)**		
	Total land area	**Surveyed land area[1]**	**Total land area**	**Surveyed land area[1]**	**Total land area**	**Surveyed land area[1]**	**Total land area**	**Surveyed land area[1]**	**Surveyed / Total**
	Million ha		Million ha		Million ha		Million ha		%
Africa	112.9	112.6	790.0	741.0	1362.6	370.4	2265.6	1 224.0	54.0
L. America	527.7	521.6	817.6	532.5	343.0	179.5	1 688.4	1 233.6	73.1
Asia	324.3	257.6	240.7	195.9	363.7	157.0	928.7	610.5	65.7
Total	964.9	891.8	1848.4	1 469.4	2069.4	706.8	4882.7	3 068.0	62.8
Surveyed / Total (%)	92.4		79.5		34.2		62.8		

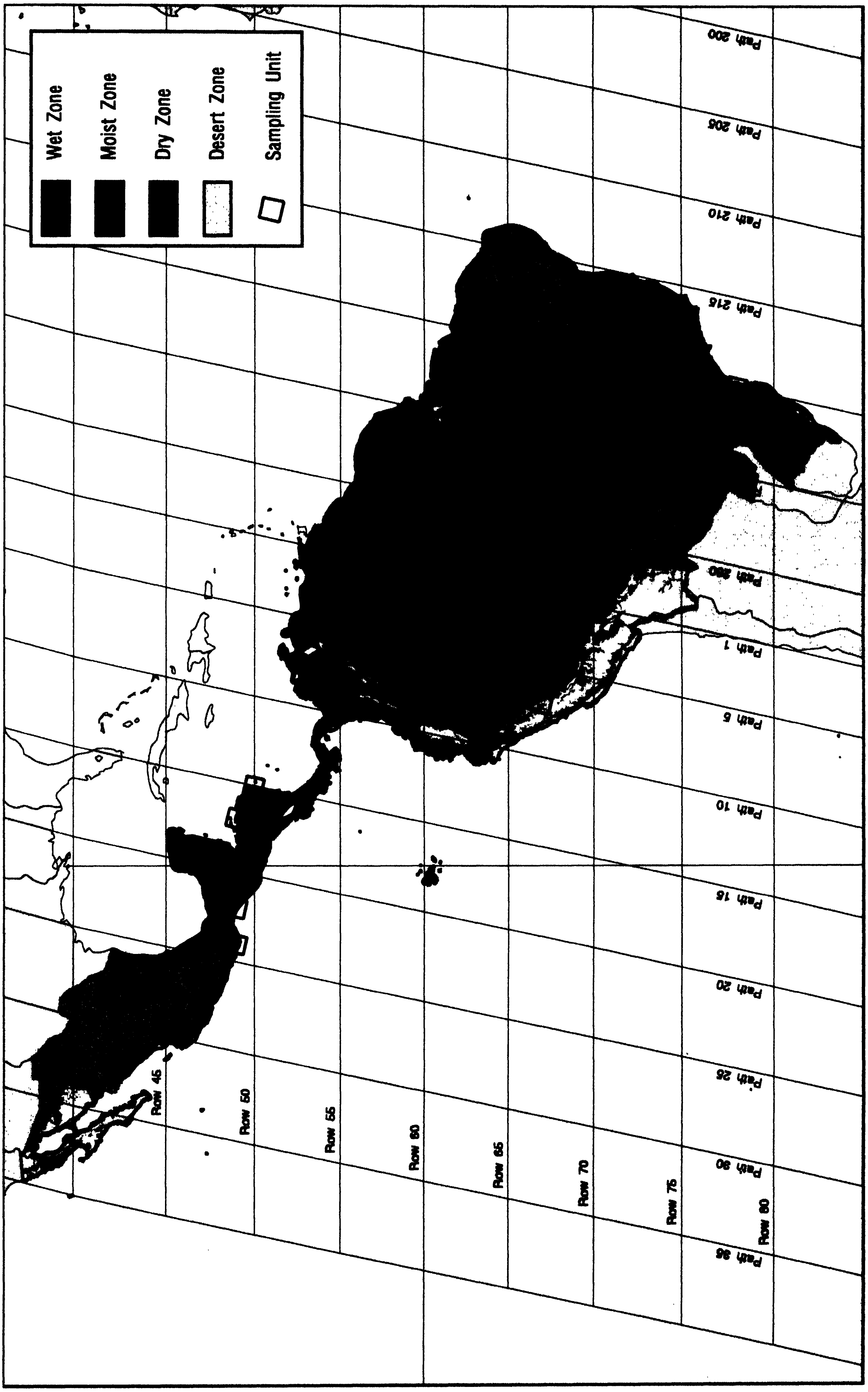
	Sampling units[2]		**Sampling intensity**	**Sampling units[2]**		**Sampling intensity**	**Sampling units[2]**		**Sampling intensity**	**Sampling units[2]**		**Sampling intensity**
	#	land area million ha	%	#	land area million ha	%	#	land area million ha	%	#	land area million ha	%
Africa	*3*	4.9	4.4	*28*	62.7	8.5	*16*	36.6	9.9	*47*	104.2	8.5
L. America	*11*	22.7	4.4	*23*	53.0	10.0	*5*	12. 1	6.7	*39*	87.8	7.1
Asia	*12*	17.9	7.0	*9*	21.2	10.8	*8*	20.2	12.9	*29*	59.3	9.7
Total	*26*	45.5	5.1	*60*	136.9	9.3	*29*	68.9	9.7	*115*	251.3	8.2

[1] The *surveyed area* indicates the area from which the sample was taken (see Sampling Design, Section. 2.1.1), which excluded Landsat scenes with less than one million hectares of land or with forest cover below 10 percent.

[2] The *sampling unit land area* represents the visible common land area of recent and historical images. The total number of SU is 115, and not 117, due to unavailability of second date coverage in two SUs.

The main climatic parameters of the three ecological zones are tabulated in Annex 16. Change matrices and flux diagrams by ecological zone are given in Annex 17, 18 and 19.


Wet Zone
Moist Zone
Dry Zone
Desert Zone
Sampling Unit
146
150
Row 45
Row 50
Row 55
Row 60
Row 65
Row 70
Row 75
Row 80
Path 155
Path 160
Path 165
Path 170
Path
Path 180
Path 185
Path 190
Path 195
Path 200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Moist Zone
Dry Zone
Desert Zone
Sampling Unit
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Path 205
Path 210
Path 215
Path 220
Path 1
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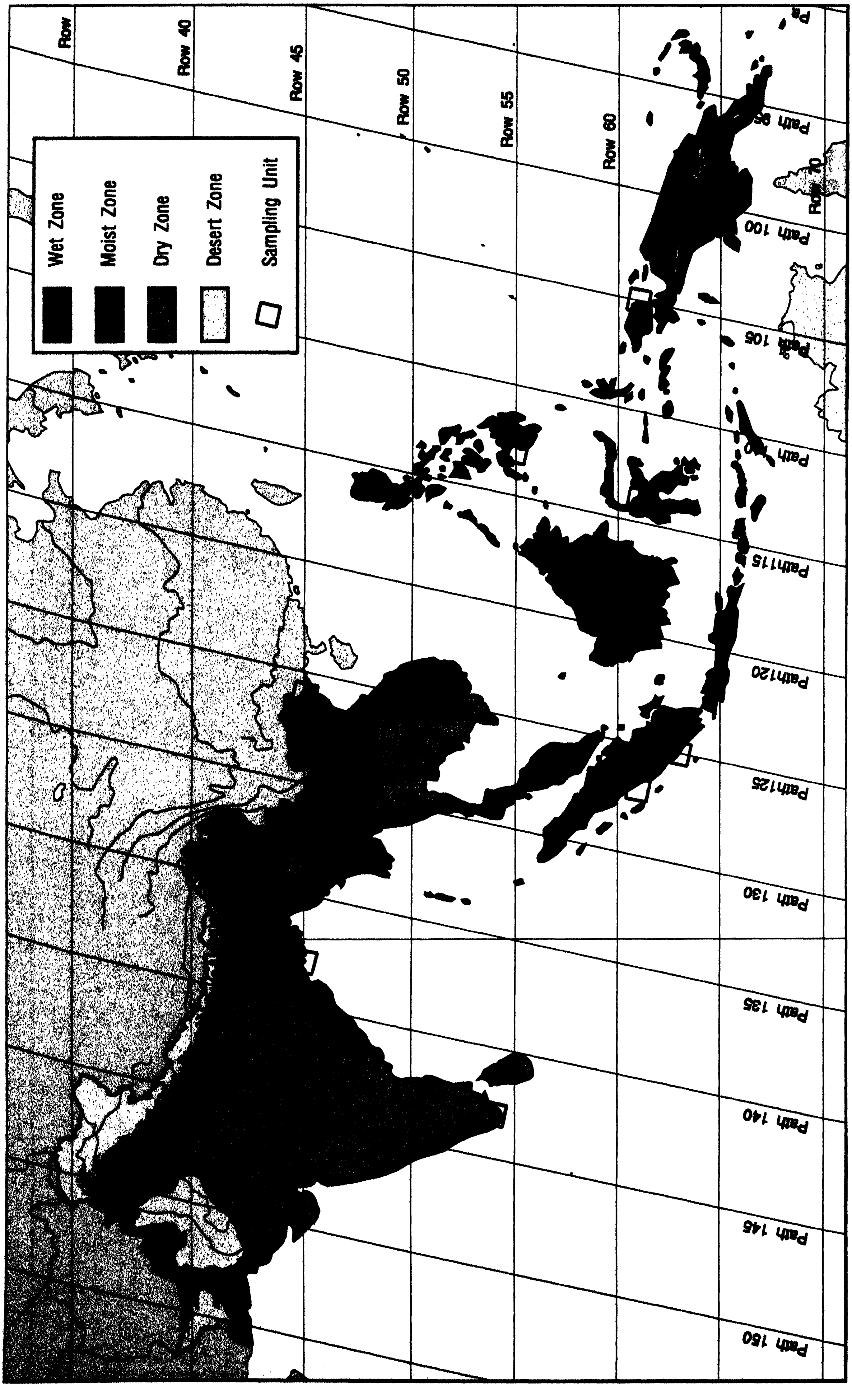
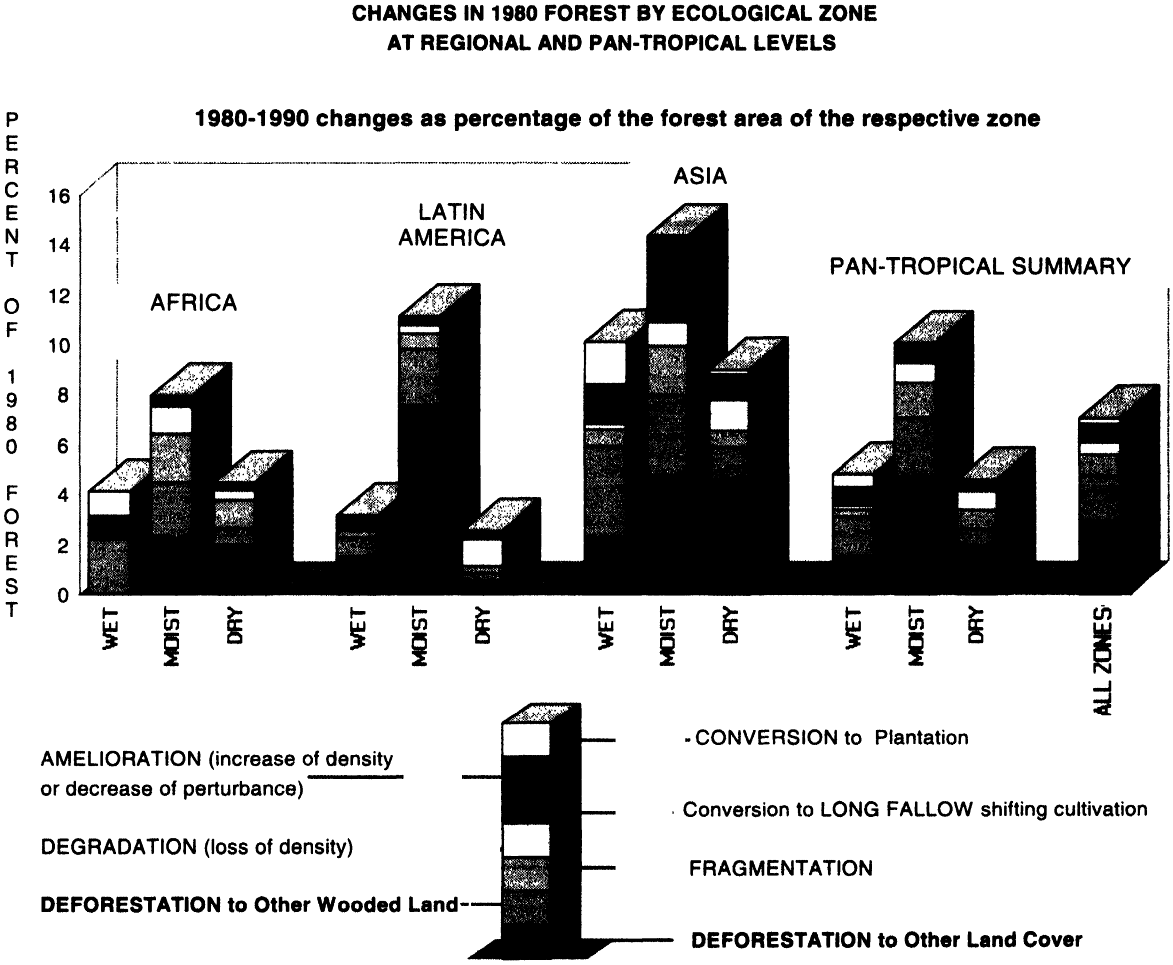


Figure (4.2.3) 1c: Asia Region - Map of Ecological Zones

As a comparative summary, Figure (4.2.3) 2 shows the main categories of change in forest cover by ecological zone for each geographical region and as a pan-tropical summary. The graph shows the areas of change as percentages of the original forest cover in 1980, thus indicating the relative level of depletion that the forests in the various ecological zones and geographical regions have undergone during the decade. By observing the pan-tropical summary the trend is very clear: the forest in the moist zone has been deforested, fragmented and degraded with a much higher intensity than in wetter and drier zones. In particular, if one considers only the frequency of the two categories of deforestation (to other land cover and to other wooded land) in the moist zone, it is more than double that of the other zones.

This can be explained by the better suitability of the moist zone for agricultural practices (and probably by the higher population density and growth) in comparison to the other zones.

Figure (4.2.3) 2: Main categories of forest change by ecological zone at regional and pan-tropical levels



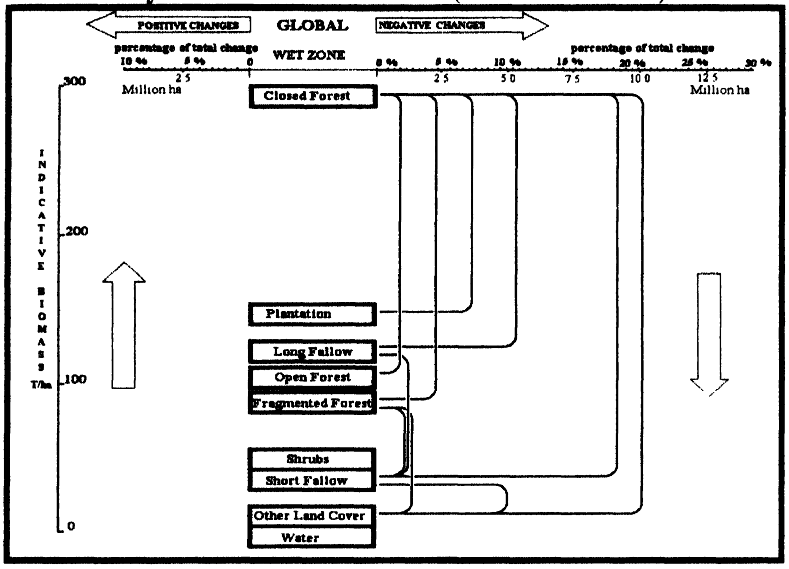
This ecological trend is also consistent with those at the regional level, as the graph clearly shows. In all regions the forests of the moist zone suffer a higher rate of depletion (see also Annex 20 for eco-regional tabulation of results). In addition, from this graph some eco-regional characteristics emerge:

- Asia has the "leadership" in overall forest change rates in all zones but the moist zone of Latin America presents the highest deforestation rates.
- Only the wet zones of Africa and Asia present consistent rates of conversion from forest to plantation .
- Conversion to long fallow shifting cultivation is significant only in Asia and particularly in the moist zone, where it is accompanied by a significant rate of amelioration (mainly represented here by long fallow reverting to closed forest).

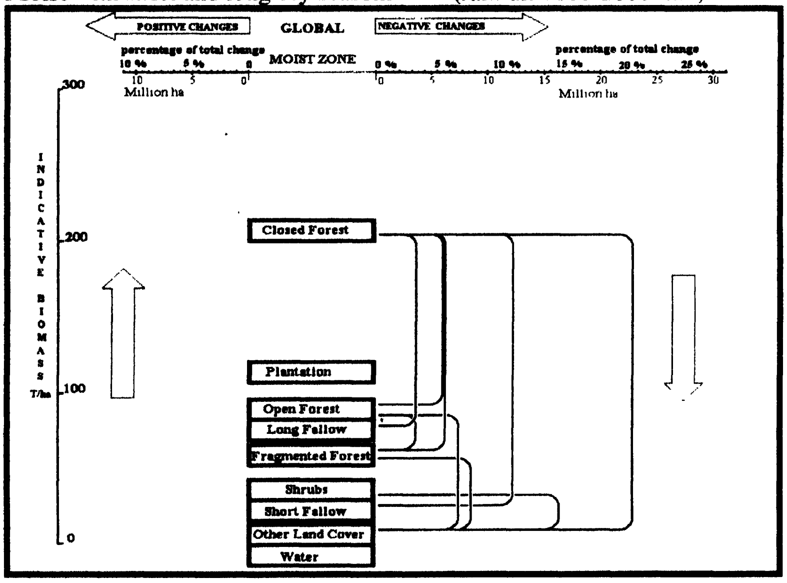
In spite of the distinctive eco-regional characteristics mentioned above it would appear that the ecological influence has a greater effect on the intensity of change rather than on its nature.

Figure (4.2.3) 3: Flux diagrams of woody biomass by ecological zone[1] (Pan-tropical overview)

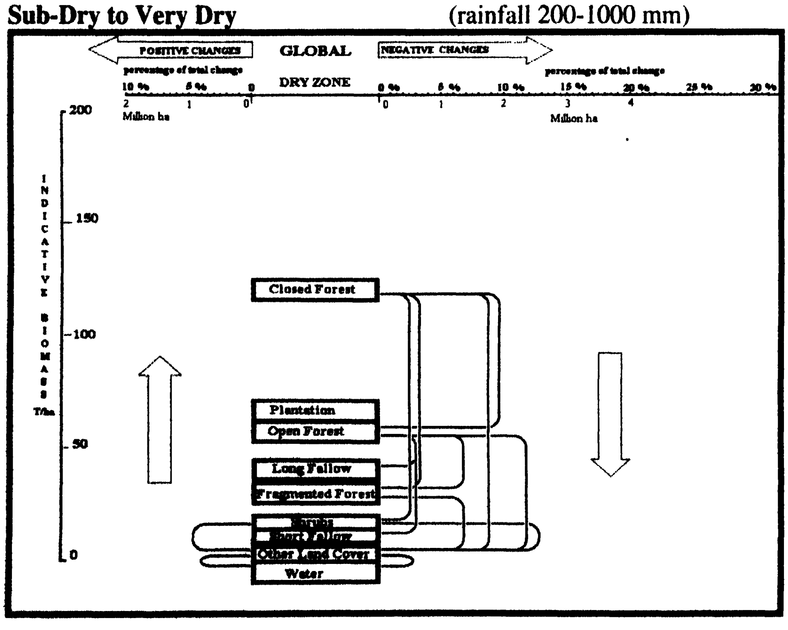
Wet and Very Moist (rainfall > 2000 mm)



Moist with short and long dry seasons (rainfall 1000-2000 mm)



Sub-Dry to Very Dry (rainfall 200-1000 mm)



An interesting additional perspective is provided when the changes are related to estimated biomass quantities. The flux diagrams of woody biomass shown in Figure (4.2.3) 3 relate the estimated changes on the X axis (double scale: (i) percentage of total change; and (ii) area in million hectares) to the indicative biomass values of the land cover classes on the Y axis, by ecological zone. These diagrams permit a comparison of the biomass losses involved in the processes of change and, indicatively, to quantify the contribution of woody biomass to the carbon cycle in each ecological zone. The quantity of biomass lost or gained in a given transition is represented by the area of the rectangle having as its base the area of the transition (X axis) and as its height the difference in biomass value between the class of destination and origin.

In comparison to the *percentage area changes* reported in the stack-bar graphs above, it is interesting to note the large difference between the biomass loss in the wet zone and in the dry zone in spite of a comparatively similar (percentage) rate of change. The moist zone shows the largest amount of biomass loss, keeping its negative leadership.

From the results available to date it would appear that socio-economic and cultural aspects determine the nature of the change process, while the ecological setting determines the intensity of change.

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[1] Only changes that account for more than two percent of the zone's change are shown. The X axis has a double scale: percentage and area. Note that area and biomass scales are variable.

4.3 STATISTICAL RESULTS BY DEFINITION OF FOREST (mean estimates and associated error of forest cover and deforestation rates)

The results for the area surveyed, presented hereafter, have been based on the interpretation of the entire recent image in each sampling unit. Sampling unit area in this câse does not correspond to that of the change matrices discussed in the previous sections. By referring to the entire recent image the land area observed amounts to 324.05 million hectares, representing an actual sampling intensity of 10.6 percent, versus the 8.2 percent intensity represented by the change matrices.

The resulting *forest* cover of each SU has been subsequently adjusted to the years 1980 and 1990 by applying the rate of change determined in the area common to both historical and recent images for each specific forest definition. Definitions of *forest* and their implications are discussed in Section 2.2.1.

In Table (4.3) 1, below, the figures at years 1980 and 1990 represent percentages of land area, while the deforestation rate represents the total area lost in ten years as a percentage of the forest cover in 1980.

These results refer to the land area from which the SUs were selected, which excluded satellite scenes with less than one million hectares of land or estimated, according to the project's pan-tropical vegetation map, to have less than ten percent forest cover (see Section 2.1.1). The area surveyed represents 62 percent of the entire tropical land area (see Annex 4), comprising some 87 percent of total tropical forests, according to most recent FORIS estimates. As a consequence, the forest cover estimates presented here cannot be directly compared to other estimates which refer to total and regional tropical countries' land area[1]. In this context, for instance, to produce a comparable global estimate, the estimated "(F2) forest cover 1990" mean of 51.73 percent, given below, would correspond to some 32 percent when referred to the total land area, and should be increased to some 36 percent on account of the 13 percent of forest excluded from the area surveyed.

Table (4.3) 1: Estimated forest cover, deforestation rates and standard errors at regional and global levels
Survey results for three different definitions of forest.

	Percentage forest cover at year 1990	Standard error of 1990 forest cover	Percentage forest cover at year 1980	Standard error of 1980 forest cover	Rate of deforestation	Standard error of rate of deforestation
F-1 : Definition of FOREST : Closed Forest						
AFRICA	24.65	±3.39	26.37	±3.63	6.52	±1.25
L. AMERICA	59.10	±2.89	63.32	±2.41	6.67	±1.48
ASIA	35.08	±2.23	39.44	±2.53	11.05	±2.24
GLOBAL	**40.58**	**±1.84**	**43.83**	**±1.81**	**7.42**	**±1.02**
F-2 : Definition of FOREST : Closed Forest + Open Forest + part Fragmented Forest						
AFRICA	43.42	±3.18	45.82	±3.29	5.23	±0.70
L. AMERICA	65.44	±3.14	69.96	±2.63	6.46	±1.39
ASIA	40.70	±2.12	45.19	±2.27	9.94	±1.84
GLOBAL	**51.73**	**±1.84**	**55.40**	**±1.75**	**6.62**	**±0.82**
F-3 : Definition of FOREST : Closed + Open Forest + Fragmented Forest + Long Fallow						
AFRICA	45.44	±3.22	47.72	±3.32	4.77	±0.61
L. AMERICA	66.83	±3.12	71.17	±2.64	6.10	±1.36
ASIA	47.48	±3.16	51.72	±3.19	8.20	±1.44
GLOBAL	**54.45**	**±1.90**	**57.94**	**±1.81**	**6.03**	**±0.75**

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[1] For a specific comparison with Phase I estimates for tropical countries, published in Forestry Papers 112 and 124 [FAO 1993 and 1995], see Section 5.1 "Relation between the Remote Sensing Survey and FORIS (FAO Forest Resources Information System) databases".

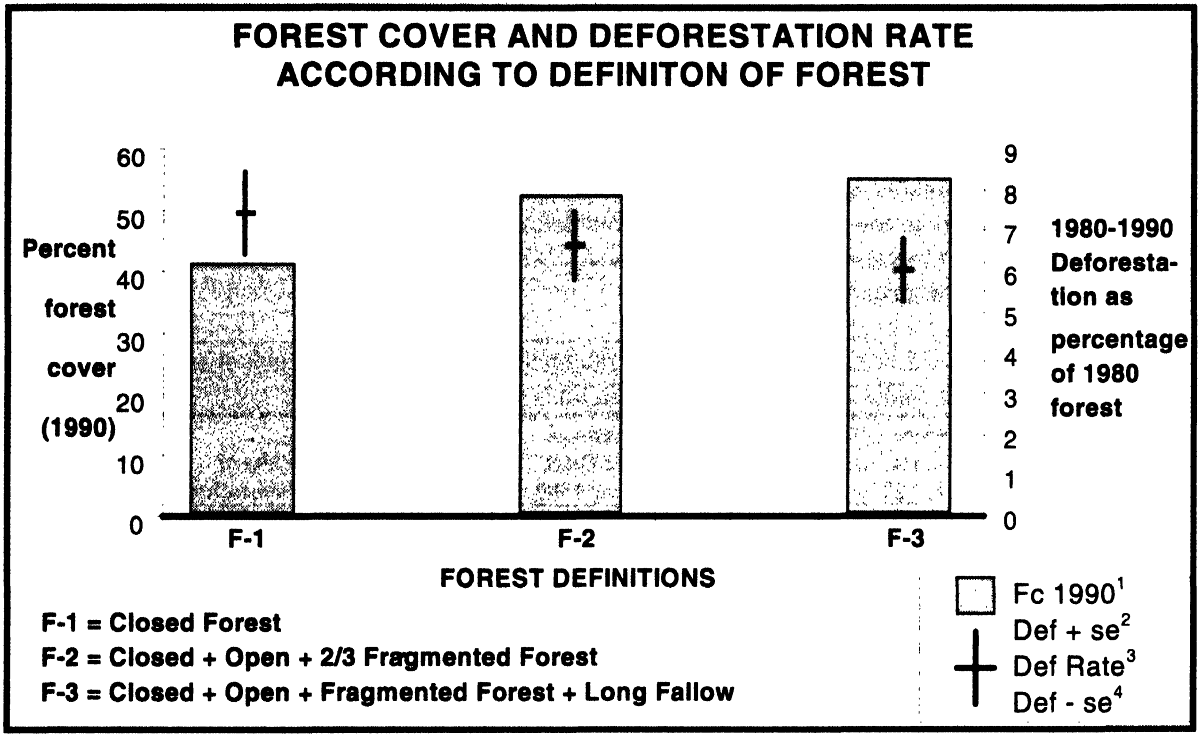
More than the mean value alone, one should consider the range of values within confidence limits, which are determined by the sampling error associated to such mean.

The statistical error associated with the global level estimates of forest cover at year 1990, ranging between ±3.5 and 4.5 percent of the mean, is quite small and very close to the ± 3.9 percent value estimated during the design phase of the survey. A higher margin of error is associated with mean deforestation rates, ranging between ±12.3 and ±13.7 percent of the mean rates. This is not too high, however, considering the high variance deriving from the 'event' character of deforestation.

Future sample rounds will progressively reduce the sampling error associated to forest cover and deforestation estimates, thus allowing the production of results at more detailed reporting levels.

The graph in Figure (4.3) 1 illustrates the relationship between forest definitions and deforestation rates, highlighting their inverse correlation.

Figure (4.3) 1: Pan-tropical forest cover and relative deforestation rate according to varying definitions of forest



[1] Estimated forest cover at year 1990, referred to Y axis on the left.

[2] Deforestation rate + standard error, referred to Y axis on the right.

[3] Mean deforestation rate, referred to Y axis on the right.

[4] Deforestation rate - standard error, referred to Y axis on the right.

There is an apparent decrease in deforestation rate with the broadening of forest definition. This is determined by the fact that the changes within the forest, when a broad forest concept is used, are classified as degradation and fragmentation and not as deforestation. The forest definitions applied in this survey and the definition of forest area changes (deforestation, degradation, fragmentation, amelioration, afforestation, etc.) are discussed in Section 2.1.1.

4.4 EVALUATION OF ERRORS

How reliable are the results of the present survey?

This question cannot be answered by a single statement. There are elements with high reliability and others with low reliability. There are errors that can be quantified and errors that cannot be quantified. It is important, therefore, to discuss all these aspects and to try to *understand* both the strengths and weaknesses of the survey. This would help not only the user of the data presented here but also those who intend to carry out similar studies in the future. A thorough understanding of the error budget is in fact an essential prerequisite for the development of survey procedures.

The features of the survey that determine the errors, or that can be considered a source of error, can be defined as follows:

(i) it is a statistical sample survey;
(ii) it is based on the interdependent observation of multi-date satellite data with the main focus on land cover changes; and
(iii) it is based on visual interpretation of satellite data, covering all ecological conditions of the tropical belt.

The first feature is a source of **sampling error** while the other two are sources of **measurement error**.

4.4.1 Statistical errors

The **sampling errors** related to the first feature, viz., the statistical sampling design, are the easiest to estimate and have been reported along with results of forest cover mean estimates and deforestation rates in Section 4.3.

Depending on the definition of *forest*, the standard errors of forest cover estimates at pan-tropical level range between ±3.5 and ±4.5 percent. It is important to highlight that the result for the intermediate definition of *forest*, which correspond more closely to the preliminary data set used during the design phase of the survey, has a standard error of ±3.6 percent, which exceeds in precision the originally defined goal of ± 3.9 percent. This shows that both the survey procedure and the sampling intensity were chosen correctly.

The standard error of the estimated rate of deforestation for the same definition of *forest* is ± 12.4 percent, much higher than that of forest cover. This can be expected, however, as deforestation has a very high coefficient of variation.

An additional source of statistical error relates to the use of dot grids for area measurement (see Section 2.4). The error in area estimates caused by dot grid measurement cannot be quantified exactly but there are empirical formulae which have been developed to obtain a good approximation of such error. Error estimation can be achieved by applying the following formula (Chevrou, 1971), reported in the Manual of Forest Inventory (Lanly, 1973), and modified slightly by Baltaxe in 1991:

$$e\,\% = 52\,(\sqrt{k} / n^{3/4})$$

where:

e %	is the percentage error of the measured area at the 95 percent probability level;
n	is the number of dots counted within the area measured; and
k	is a factor which depends upon the shape of the area and the regularity of its boundary; its value is between 5 and 7 for regular shapes and increases with the irregularity of the boundary.

As the land area studied in the present survey is quite large (324.05 million hectares, corresponding to 810 112 dots), and all class measurements have been based on many dots, errors can be considered negligible even when choosing a high k value of 8, as shown in Table (4.4.1) 1:

Table (4.4.1) 1: Estimated error of area due to dot grid measurement (Class areas refer to year 1990 at pan-tropical level)

	Closed Forest	Open Forest	Long Fallow	Frag-mented Forest	Shrubs	Short Fallow	Other Land Cover	Planta-tions	Total
Dot counted	262 156	60 296	12 454	36 187	32 775	30 714	188 602	4 308	627 492
Estimated e %	0.01	0.04	0.12	0.06	0.06	0.06	0.02	0.28	0.007

4.4.2 Change estimate errors

The measurement error related to the second feature, viz., change assessment, can be of paramount importance. In a comparison of two **independent** observations, the error associated with the change is higher than the error associated with the two original observations, as the law of propagation of error postulates. In the case of changes of small magnitude the resulting error could be too high to be acceptable.

In consideration of this problem the methodology developed for the assessment of class transitions was based on an **interdependent** interpretation procedure (see Section 2.3). This procedure ensured the highest level of consistency between the classification of recent and historical images. As a result of this approach the measurement error associated with class transitions can be minimized and remains comparable to that of the recent and historical classifications, as shown in the formulation below:

Errors in the estimation of change
INDEPENDENT versus INTERDEPENDENT interpretation approach

X_1 = Interpretation at date 1
X_2 = Interpretation at date 2
Y_1 = true class at date 1
Y_2 = true class at date 2

ε_1 = noise of image (date 1)
ε_2 = noise of image (date 2)
μ_1 = error of interpretation (date 1)
μ_2 = error of interpretation (date 2)

$(\varepsilon_1 + \mu_1)$ and $(\varepsilon_2 + \mu_2)$ are the errors 'e'.
ε and μ may be positively correlated; i.e., much noise in the image makes the interpretation more uncertain.

Therefore: $\mathrm{Var}(\varepsilon_1 + \mu_1) = \sigma_\varepsilon^2 + \sigma_\mu^2 + 2\mathrm{Kov}(\varepsilon_1,\mu_1) = \sigma_e^2$
Assumption: independence between images.

Independent interpretation

$X_1 = Y_1 + \varepsilon_1 + \mu_1$ Interpretation at date 1
$X_2 = Y_2 + \varepsilon_2 + \mu_2$ Interpretation at date 2
$X_1 - X_2 = Y_1 - Y_2 + \varepsilon_1 - \varepsilon_2 + \mu_1 - \mu_2$ Change estimation
VAR (state estimation) = $\sigma_\varepsilon^2 + \sigma_\mu^2 + 2\mathrm{Kov}(\varepsilon,\mu) = \sigma_e^2$
VAR (change estimation) = $2\sigma_\varepsilon^2 + 2\sigma_\mu^2 + 4\mathrm{Kov}(\varepsilon,\mu) = 2\sigma_e^2$

Interdependent interpretation

$X_1 = Y_1 + \varepsilon_1 + (\mu_1+\mu_2)/2$ Interpretation at date 1
$X_2 = Y_2 + \varepsilon_2 + (\mu_1+\mu_2)/2$ Interpretation at date 2

VAR (**state estimation where there is no change**; i.e., $Y_1=Y_2$)
classification according to: $X = (X_1+X_2)/2 = Y_1 + (\mu_1+\mu_2)/2 + (\varepsilon_1+\varepsilon_2)/2$
$\mathrm{Var}(X) = \sigma_\varepsilon^2/2 + \sigma_\mu^2/2 + (2\mathrm{Kov}(\varepsilon,\mu))/2 = \sigma_e^2/2$

VAR (**state estimation where the class has changed**)
classification according to: $X_2 = Y_2 + \varepsilon_2 + (\mu_1+\mu_2)/2$
$\mathrm{Var} = \sigma_\varepsilon^2 + \sigma_\mu^2/2 + \mathrm{Kov}(\varepsilon_2, \mu_2) = \sigma_e^2/2 + \sigma_\varepsilon^2/2$

VAR (**change estimation**) = $\mathrm{Var}(\varepsilon_2 - \varepsilon_1) = 2\sigma_\varepsilon^2$

From the above formulation it would appear that the interdependent approach, where both images are used throughout the interpretation process, is beneficial not only in terms of change assessment but also in state assessment as the consultation of both images provides additional evidence in support of the delineation of the classes in both historical and recent images, as discussed in detail in Section 2.3.

4.4.3 Classification errors

The measurement error related to the interpretation accuracy of all 117 sampling units is very difficult to quantify. In fact, the accuracy of each interpretation could have been estimated exclusively on the basis of "true" reference (i.e. ground truth) collected in each study area at a very high cost; moreover, it is virtually impossible to estimate the interpretation accuracy of historical images.

Nevertheless, it is possible and important to associate the results with a critical evaluation of their reliability based on experience and on "educated guesses". Following an approach similar to the fuzzy set theory (Zadeh, 1965; Gopal and Woodcock, 1994) it is possible to rank the results at various levels of reliability on the basis of some specific assumptions. Given an adequate knowledge of the study area, a good and coherent perception of the classification used and an acceptable image quality, it can be assumed that:

- a class is delineated with higher reliability where the contrast with the surrounding classes is sharper. Similarly, a change is more reliable when there is a sharp contrast between the original land cover class and the final one;
- the tonal intensity of vegetation cover classes is directly related to biomass density. Therefore, the reliability of class delineation (or class change) is higher where the biomass gradient with the surrounding classes (or with the original class) is greater; and
- the biomass density of vegetation cover classes is a function of the ecological character of the specific area studied.

Following the above assumptions an estimated (indicative) biomass value has been allocated to each land cover class for each of the three broad ecological zones defined in the previous chapter. This value represents aboveground woody vegetation biomass in tonnes per hectare. These values have been defined on the basis of the best available information on average biomass values of closed and open forest classes by ecological zone; the values for the remaining classes in each zone were derived from these two "biomass indicators", as explained in Section 2.8.

The Tables in Annex 8 give, in the form of transition matrices for each ecological zone, the estimated biomass difference (in absolute value) for all possible class-to-class combinations. This difference is here termed as *biomass gradient*. The values thus determined can be used in two different contexts:

- **Spatially** - the biomass gradient indicates the contrast between two adjacent classes and the probable "sharpness" or reliability of such a boundary.
- **Temporally** - when comparing the same area at two points in time (on historical and recent satellite images) the biomass gradient indicates the difference between the two situations and, therefore, the "sharpness" or reliability of a given class-to-class transition.

Table (4.4.3) 1 provides a reliability ranking for the land cover classes in three ecological zones by stratifying the biomass gradients into three groups on the basis of their magnitude. Arbitrarily, the class relations (in space and in time) with a biomass gradient *above 100 tonnes* have been ranked as **1** (***high reliability***), those with biomass gradient *between 50 and 100 tonnes* as **2** (***medium reliability***) and those with a biomass gradient *below 50 tonnes* as **3** (***low reliability***). In view of its distinct spectral signature the class *water* and all combinations involving it are considered of high reliability.

The estimation of reliability applies equally to the spatial aspect (state assessment) and to the temporal aspect (change assessment); in the former, it represents the reliability in class delineation as a function of the contrast among adjoining classes, while in the latter it represents the reliability of class transition as a function of the contrast between the land cover class at date one and the class at date two.

Table (4.4.3) 1: Reliability ranking

1 = High reliability (Biomass gradient >= 100 tonnes/ha)
2 = Medium reliability (Biomass gradient 50 - 100 tonnes/ha)
3 = Low reliability (Biomass gradient < 50 tonnes/ha)

Ecological zone: **WET and VERY MOIST**

Land Cover Categories	Land Cover Classes	**Continuous Natural Forest** Closed Forest	Open Forest	Long Fallow	**Frag-mented Forest**	**Other Wooded** Shrubs	Short Fallow	**Non-Wooded** Other Land Cover	Water	**Plan-tation**
Continuous Natural Forest	Closed Forest		1	1	1	1	1	1	1	1
	Open Forest	1		3	2	2	2	2	1	2
	Long Fallow	1	3		3	2	2	1	1	3
Fragmented Forest		1	2	3		3	2	2	1	2
Other Wooded	Shrubs	1	2	2	3		3	3	1	1
	Short Fallow	1	2	2	2	3		3	1	1
Non-Wooded	Other Land Cover	1	2	1	2	3	3		1	1
	Water	1	1	1	1	1	1	1		1
Plantation		1	2	3	2	1	1	1	1	

Ecological zone: **MOIST with short and long dry season**

Land Cover Categories	Land Cover Classes	**Continuous Natural Forest** Closed Forest	Open Forest	Long Fallow	**Frag-mented Forest**	**Other Wooded** Shrubs	Short Fallow	**Non-Wooded** Other Land Cover	Water	**Plan-tation**
Continuous Natural Forest	Closed Forest		1	1	1	1	1	1	1	1
	Open Forest	1		3	2	2	2	2	1	3
	Long Fallow	1	3		3	3	2	2	1	3
Fragmented Forest		1	2	3		3	3	2	1	3
Other Wooded	Shrubs	1	2	3	3		3	3	1	2
	Short Fallow	1	2	2	3	3		3	1	2
Non-Wooded	Other Land Cover	1	2	2	2	3	3		1	2
	Water	1	1	1	1	1	1	1		1
Plantation		1	3	3	3	2	2	2	1	

Ecological zone: **SUB-DRY to VERY DRY**

Land Cover Categories	Land Cover Classes	**Continuous Natural Forest** Closed Forest	Open Forest	Long Fallow	**Frag-mented Forest**	**Other Wooded** Shrubs	Short Fallow	**Non-Wooded** Other Land Cover	Water	**Plan-tation**
Continuous Natural Forest	Closed Forest		2	2	2	1	1	1	1	3
	Open Forest	2		3	3	3	2	2	1	3
	Long Fallow	2	3		3	3	3	3	1	2
Fragmented Forest		2	3	3		3	3	3	1	2
Other Wooded	Shrubs	1	3	3	3		3	3	1	2
	Short Fallow	1	2	3	3	3		3	1	2
Non-Wooded	Other Land Cover	1	2	3	3	3	3		1	2
	Water	1	1	1	1	1	1	1		1
Plantation		3	3	2	2	2	2	2	1	

Frequency of class transition (Percentage of total change in each ecological zone)

No box = less than 1 percent ☐ **1 to 5 percent** ▢ **5 to 10 percent** ▨ **Over 10 percent**

However, the reliability of classification (spatial aspect) is more difficult to relate to the final results discussed here since it depends mainly on the spatial relation existing among classes, which can only be seen on the spatial outputs of each individual SU. On the contrary, this estimation of class transitions reliability relates perfectly to the results since the change matrices report all class-to-class transitions originally observed in each SU.

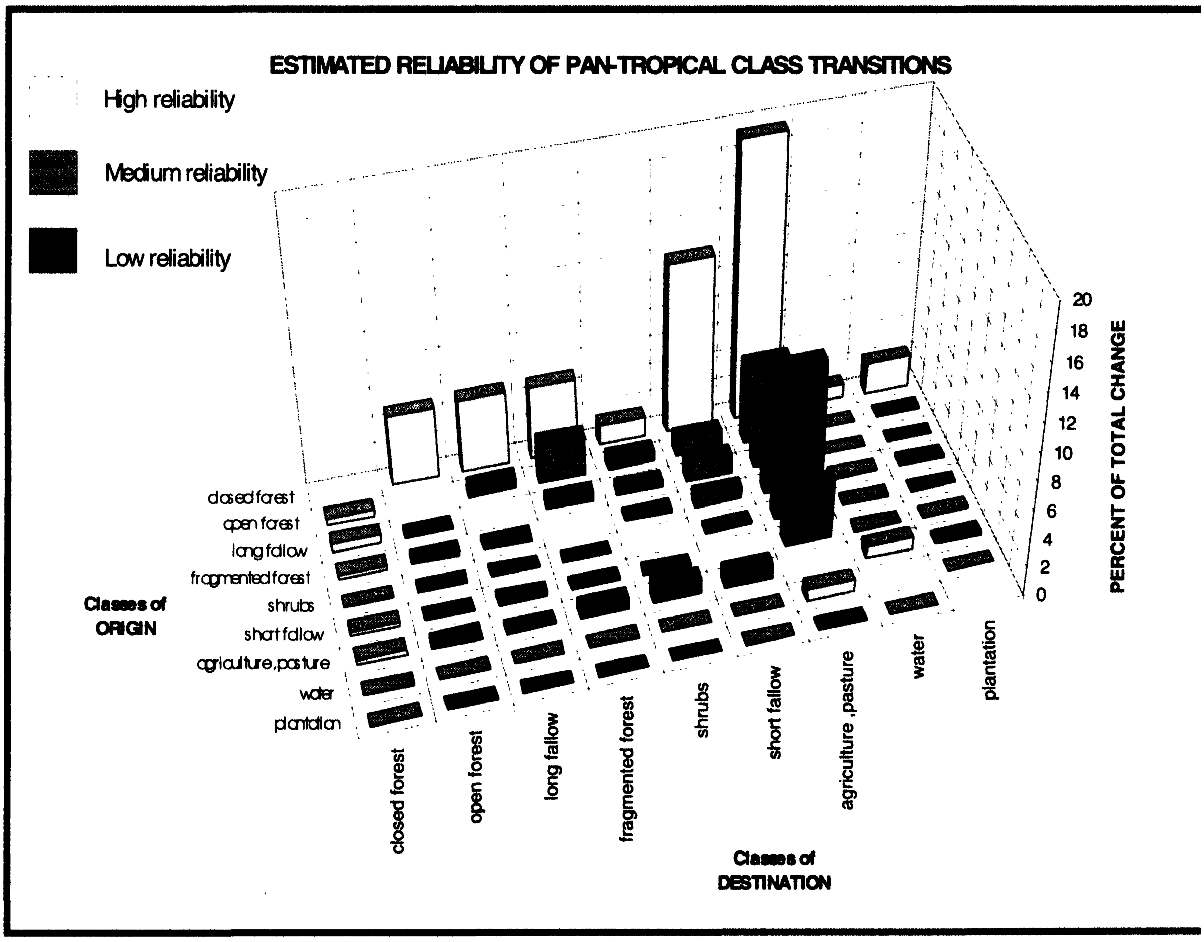
In order to concentrate attention on the most frequent changes, Table (4.4.3) 1 indicates the class transitions that account for less than one percent of the total change observed in that particular zone, those representing between one and five percent, those representing between five and ten percent and the most important ones, representing more than ten percent of the total change.

Some comments:

- It appears that there is an overall decline in reliability in drier ecological conditions where the range of biomass values is narrower.
- The changes in forest area, and in particular in *closed forest*, are prevalently of high reliability in wet and moist conditions, and of medium reliability in dry conditions.
- The changes frequently observed, but considered of low reliability, are those from *shrubs* and *short fallow* to *other land cover* and vice versa.

Figure (4.4.3) 1 shows the indicative reliability of class transitions, of the pan-tropical change matrix, in relation to the number of changes observed. The pan-tropical reliability ranking has been estimated as the average of the three ecological zones weighted on the transition areas observed.

Figure (4.4.3) 1: Estimated reliability of pan-tropical class transitions



Although not an estimation of accuracy, this figure can serve as a useful guide when using the results presented or considering specific class transitions.

Chapter V

Relation Between the FRA 1990 RS Survey and Other Survey Efforts on Forest Resources Monitoring

Several programmes are presently under way, which share the broad common objectives of assessing and monitoring tropical forest resources and the aim to provide the international community with appropriate information to facilitate the development of adequate forest policies and to support remedial action in those areas where forest depletion is evident. However, there are wide variations on how this common goal is perceived, which mensurational approaches are adopted, what information is considered adequate, and even on what can be defined as *tropical forest.*

In order to define the range of validity of these different survey efforts, to assess the comparability of their results and gauge their possible complementarity, it is essential that one understand their main distinctive features. Table (5) 1 summarizes some basic features of four large-scale surveys.

Table (5) 1: Main features of four large-scale tropical forest resources surveys

	Study area •	**Data sources and temporal references**	**Coverage**	**Land cover classification**	**Change classification**	**State of progress**
FAO-FORIS (Forest Resources Information System)	All tropical and non-tropical developing countries	Existing national and sub-national surveys. Single date and multi-date	Complete, at sub-national level	Forest Non-forest (closed forest open forest woodlands plantations)	Deforestation (afforestation) based on forest-non forest classification	Survey completed and published (FAO, 1993) for tropical developing countries
FAO-RS Survey	Entire tropical zone	Multi-date Landsat images. Close to 1980 and close to 1990	Sample of 10% to be increased in future survey rounds	Closed forest Open forest Long fallow Fragmented for. Shrubs Short fallow Other land cover Water Plantation	9x9 possible transitions, including: Deforestation Fragmentation Degradation Amelioration Afforestation and others	First sampling round completed
TREES Phase I	Humid tropics	Multi-date NOAA AVHRR 1 km resolution (LAC or HRPT) dated 1990-93 + ERS SAR data 100 m resol. 1994	AVHRR Wall to wall (complete) ERS SAR full mosaic of Central Africa	Dense evergreen forest; Fragmented evergreen. forest; Dense seasonal forest; Non-forest	Not done as yet but planned in TREES Phase II (starting 1996)	Forest map of humid tropics completed (1 km resolution) - Analysis of ERS Africa mosaic in progress
LANDSAT Pathfinder	Humid areas of: Amazon and Orinoco basins; Central Africa; SE continental Asia and West Indonesia	Multi-date Landsat images. Mid '70s, '80s and '90s	All Landsat images taken on appropriate dates available for the study area	Forest Non-forest (in some areas also deforestation and regrowth)	Deforestation (afforestation and, in places, regrowth)	Mid '80s coverage under completion for America and Asia; remaining dates and areas in progress

The first two large-scale surveys represent Phase I and Phase II, respectively, of the FAO Forest Resources Assessment 1990 Project; the third one refers to the Project TREES Phase I (Tropical Ecosystem Environment Observation by Satellite) by the Joint Research Centre of the Commission of the European Community; the fourth one refers to the NASA LANDSAT Pathfinder Tropical Deforestation Project, a collaborative research effort carried out under the auspices of the University of New Hampshire, the University of Maryland and the NASA Goddard Space Flight Center.

In order to avoid duplication of work and achieve the synergetic harmonization of all these efforts, and thus to meet more efficiently the underlying common objectives, it is necessary to review the distinctive features of each survey and analyze promising levels of integration.

5.1 RELATION BETWEEN THE REMOTE SENSING SURVEY AND FORIS (FAO Forest Resources Information System) DATABASES

As reported in several documents of the Organization (FAO Forestry Papers 112 and 124) and in the Introduction to the present report, two distinct complementary approaches have been followed by the Forest Resources Assessment 1990 Project to determine the extent of tropical forest cover and its rate of change:

- The first approach was based on the analysis and harmonization of **existing information** at national and sub-national levels, resulting in the FORIS (Forest Resources Information System), a spatial and statistical database reporting forest cover and deforestation rates for all tropical countries, presented in FAO Forestry Papers 112 and 124. These results represent the harmonized synthesis of a large amount of **heterogeneous** information.
- The second approach was based on **new information** gathered from multi-date satellite data in the frame of a statistical continuous forest inventory design (of which the 117 SUs represent the first sample round, resulting in the set of data presented and discussed in the present document). These results represent the synthesis of **homogeneous** sample observations. This approach was designed to counter-balance the shortcomings of the first approach and not to replace it.

As expected, the results of the two approaches are different, which may create some confusion for the users of FAO data. The purpose of this section is to guide the user by highlighting their distinctive characters, clarifying their scope and their complementary role in a new forest resources estimation system.

Data sources

The data sources of the FORIS database range from repetitive and highly accurate inventories to non-documented single date estimates of varying, and often unknown, reliability. The mapping scale of such data is also quite heterogeneous. This variability prevents the assessment of overall FORIS accuracy or spatial resolution but it remains an irreplaceable compendium of the best information available at national and sub-national levels.

The present RS survey, being consistent in terms of data sources used (Landsat data), approach and resolution, makes the assessment of statistical and non-statistical errors, if not easy, possible.

Classification

From a global viewpoint there is little consistency among the classifications adopted in national or sub-national surveys which, in view of their original scope, applied purposive definitions of "forest", often subject to national perspectives. Countries with large areas of rich forest tend to exclude from their statistics sparse and fragmented formations while countries with only sparse formations tend to do the opposite.

The RS survey have overcome this problem by adopting a standard classification system, sufficiently detailed to describe consistently the entire range of forest conditions and change processes encountered in the tropics.

Temporal resolution

The reference years of FORIS data sources range between the early 1970s and the late 1980s, with an approximate mean around 1981; in addition, multitemporal observations exist for only 21 of 90 countries surveyed (see Table (1.4) 1 in the Introduction), and such observations are not distributed homogeneously among the geographic regions. These factors are very important in the estimation of deforestation rates during the 1980-1990 period. As the existing country level data set resulted to be, on average, rather out-of-date, one had to resort to the use of mathematical models or adjustment functions to bring forest areas and deforestation rates to the desired reporting period. The risk exists, however, of introducing a certain bias due to (i) the period covered by the existing multitemporal data set; and (ii) the unbalanced geographic distribution of such multitemporal data sets.

Reference dates of RS observations are much closer to the 1980-1990 reporting period although satellite image availability often imposed a certain deviation (see Figure (2.5) 1, Section 2.5, and the list of images in Annex (3.1) 1). The integration of the RS sampling units with the national multitemporal data sets in developing regional models will improve greatly both their precision and temporal consistency.

Thematic resolution (deforestation versus processes of change)

The heterogeneity of classifications peculiar to FORIS sources and the poor consistency of most multi-date data sets placed a heavy toll on the thematic resolution of the final results. Practically only *forest* for the state and *deforestation* for the change were applied; these are terms which, in spite of their neatness, carry a lot of ambiguity.

On the contrary, the RS results achieved an unprecedented level of thematic resolution in the analysis of pan-tropical changes, thanks to the consistency of the classification used and the interdependent interpretation of multi-date satellite data. In addition to quantitative estimates of deforestation, for example, the RS survey provides, with its change matrices, valuable insight into the change processes which helps one to understand their dynamics.

Range of validity

FORIS reports country level data but also includes sub-national level information in its statistical and spatial databases. Its thorough wall-to-wall coverage and sub-national statistical and spatial data allow for detailed analyses carried out in combination with socio-economic, demographic and eco-floristic information layers. In this respect, it is unique and irreplaceable.

RS results represent the first round of a continuous pan-tropical survey based on a ten percent sample. With this sampling intensity the results are reliable at pan-tropical and regional levels, where they show relatively small sampling errors. RS results do not replace the FORIS country estimates but can contribute significantly to the description of both regional and ecological trends. With subsequent sample rounds, in the future, the reporting units can be reduced to sub-regional level and will include analysis of variations in rates of change.

Comparison of FORIS and RS estimates

The results of the RS survey and FORIS cannot be directly compared in view of the differing land area of reference. The RS results refer to the land area from which the SUs were selected, which excluded, from all satellite scenes covering the tropical regions, those scenes with less than one million hectares of land or estimated, according to the project's pan-tropical vegetation map, to have less than ten percent forest cover (see Section 2.1.1). The land area actually surveyed represents 62 percent of the entire tropics.

A comparison can be made only when the results of both approaches refer to the same land area. In order to achieve this consistency, FORIS statistical data, viz., forest cover and deforestation rate by sub-national unit, had to be distributed spatially to match the RS surveyed land area. Such spatial distribution of FORIS data by nominal Landsat scenes was carried out through intermediate spatial variables derived from the project's pan-tropical vegetation map. This process of "spatialization" (M. Lorenzini and A. Marzoli, 1994) is based on a multi-variate analysis of correlation between FORIS sub-national statistics and the (64!) classes of the vegetation map. As a result of this analytical process, the area of forest and the area of deforestation of the FORIS database could be distributed spatially and, subsequently, cut into Landsat frames.

Although at local level (single Landsat frames or small aggregations) the error of "spatialization" could be significant, due to the limitations of scale, 1:5 million, and classification of the vegetation map, it was considered that for larger areas the results of this process were acceptable and, particularly, that their accuracy improved with the size of the aggregation.

Figure (5.1) 1 a and b show the stratum level estimates of forest cover and deforestation rates from RS and FORIS for the sampling frame from which sampling units were selected (see Section 2.1 "Statistical Design"). The RS definition of forest adopted here corresponds to the intermediate F2 definition (described in Section 2.1.1), that better matches the FORIS standard definition. According to this definition, the land cover classes that constitute the *forest* are:

closed forest + open forest + 2/3 of fragmented forest

The correlation coefficient of FORIS and RS *forest cover* estimates at stratum level is 0.969, while that for *deforestation* estimates is 0.793. In spite of the elements that distinguish the two estimation approaches, the two sets of data are highly correlated, particularly for *forest cover* estimates. In view of the strong common ground represented by the highly-correlated *forest cover*, and in consideration of the limitations of the multi-date FORIS database, the lower correlation of *deforestation* estimates indicates that there is both scope for, and need of, further analysis and, probably, that the RS *deforestation* estimates could contribute significantly to the refinement of FORIS change estimates.

A comparison of pan-tropical FORIS and RS *forest cover* estimates at the years 1980 and 1990 is given in Figure (5.1) 2. The correspondence between mean RS and FORIS estimates is so high to be almost identical; this fact, however, should not be over-emphasized since the forest cover, at 95 percent probability, is not exactly the mean, rather it lies anywhere within the error margin, defined here as plus or minus two times the standard error.

In Figure (5.1) 3 the comparison is between FORIS and RS regional forest cover estimates for the year 1990. At regional level the correspondence between FORIS and RS estimates is lower, but still significant. Two elements probably concur to make the discrepancies in regional forest cover estimates: (i) sampling intensity at regional level, which is less than optimal; and (ii) discrepancies in forest classifications between the national statistics, base of FORIS data, and the RS classification.

Figure (5.1) 1 a, b: Correlation between RS and FORIS estimates of (a) forest cover area and (b) deforestation area for the whole pan-tropical sampling frame

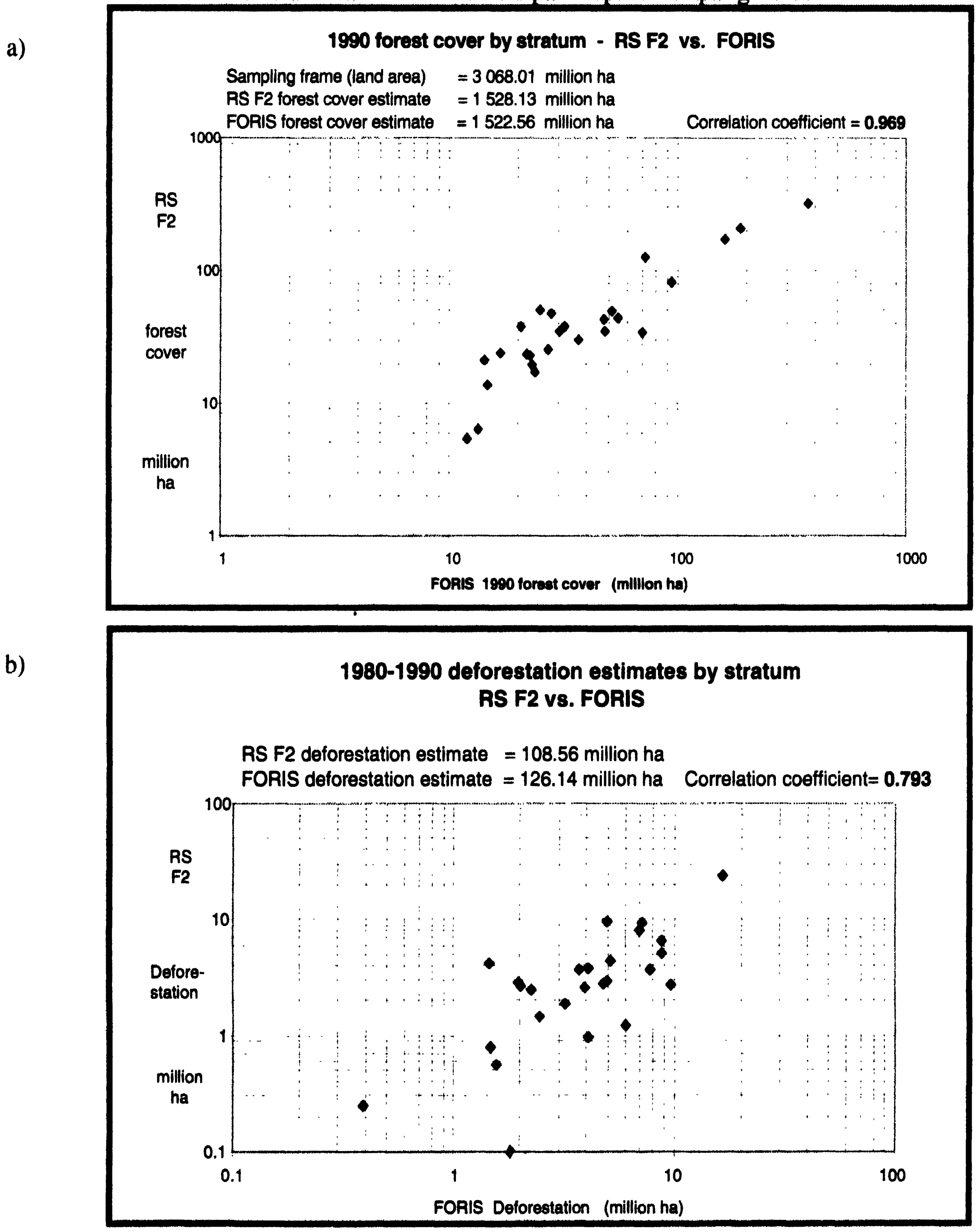


Figure (5.1) 2: Comparison of FORIS and RS forest area estimates at years 1980 and 1990 Pan-tropical level (RS sampling frame)

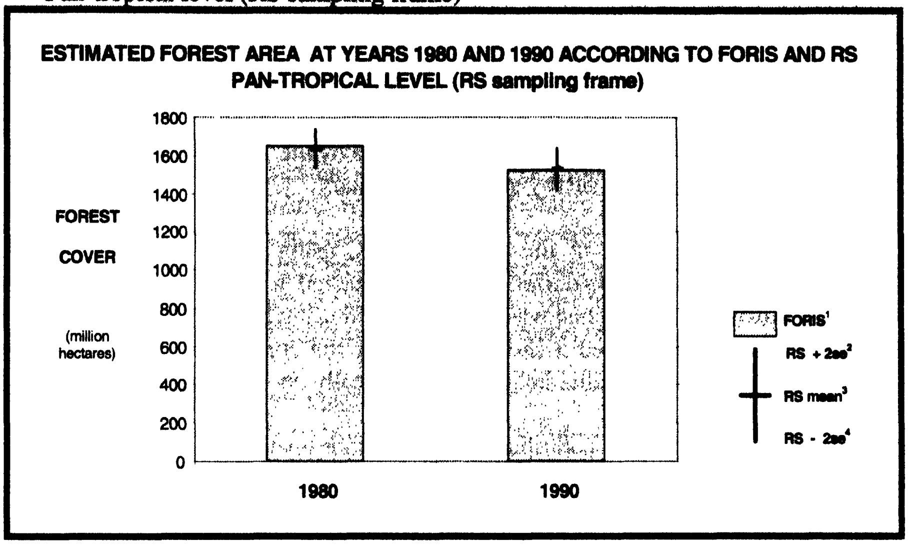
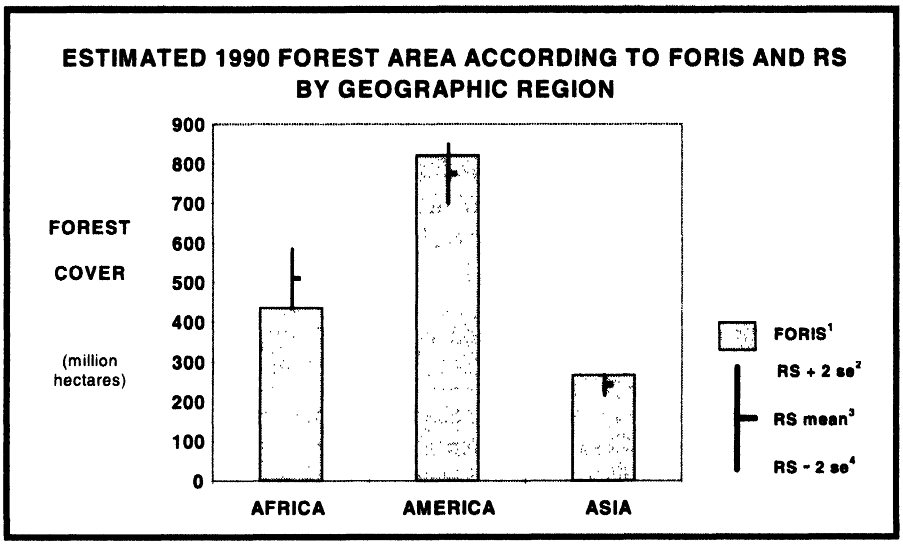


Figure (5.1) 3: Comparison of FORIS and RS forest area estimates at year 1990 by geographic region



[1] Estimates based on Forest Resources Information System (FORIS) database.
[2] Mean forest cover (definition F2) **plus** two standard errors based on remote sensing results (RS).
[3] Mean forest cover (definition F2) based on pan-tropical remote sensing survey (RS).
[4] Mean forest cover (definition F2) **minus** two standard errors based on remote sensing results (RS).

Complementarity and integration

From the aspects described above, it is evident that there is a strong complementarity between the two approaches and, at the same time, a strong correlation, as shown in the two graphs in Figure (5.1) 1. This correlation would be best exploited by integrating the two data sets into a unique **two-phase resource estimation system.**

The integration of the two data sets, which has yet to be carried out, will result in: (i) more reliable prediction models and, consequently, more detailed, homogeneous and up-to-date country level data; and (ii) more efficient stratification systems to optimize future sample rounds and the expansion of RS results.

5.2 RELATION TO OTHER GLOBAL EFFORTS ON FOREST RESOURCES MONITORING

Project TREES Phase I (Tropical Ecosystem Environment Observation by Satellite)

From a technical point of view, the approach followed by the TREES Project and that followed by the FRA 1990 Project's remote sensing survey are complementary:

- a complete mapping of the forest of the humid tropics, using coarse resolution satellite imagery (AVHRR LAC data with 1 km resolution), has been achieved within the framework of the TREES Project; the "wall-to-wall" map obtained was then calibrated using high resolution samples; and
- the FRA 1990 Project has developed a survey design for the continuous monitoring of forest cover using multi-date high resolution satellite imagery at statistically chosen sample locations.

With the wider objective of contributing to the coordination of international survey efforts (namely those of the United Nations and the European Commission) related to the monitoring of tropical deforestation and degradation, the two projects have always cooperated closely and have identified areas of integration, of data and methodologies, that will be of mutual benefits. The strengthening of technical links between the two projects is now being formalized into a cooperative operational programme, with the following objectives:

1. Integration of TREES' results and TFIS data (Tropical Forest Information System) into the FORIS database of the FRA 1990 Project and integration of FORIS databases and RS results with the TFIS of the TREES Project.
2. Use of the NOAA-based forest map and other relevant TREES data to optimize the FRA 1990 Project's high resolution survey approach which would, in addition to improving its focus on forest area changes, satisfy the TREES' requirements for map validation and calibration.
3. Improve TREES' calibration phase and contribute, with the high resolution change maps, to the development of spatial and statistical modelling of forest cover change and to the identification of areas exposed to a high risk of deforestation.

The linkage with the TREES' programme is well defined, particularly in view of the clear complementarity of the two approaches, and could be integrated into a cooperative multi-phase global survey.

NASA LANDSAT Pathfinder Tropical Deforestation Project

The Pathfinder Project is presently progressing with the classification of the first layer of Landsat data, with the mid 1980s as the time reference (see Table (5) 1). Multi-date analysis has been carried out, up to the present, for the Brazilian Amazon Basin, based on Landsat data acquired around years 1978 and 1988. The mid '80s forest cover classification will be followed by a historical layer, based on Landsat data of the mid 1970s, and by a recent one based on Landsat data of the early 1990s.

In addition to the forest cover maps derived from the classification of Landsat data, an important contribution made by this project to the community of investigators, involved both in local and global level studies, consists of the large archive of multi-date Landsat data being built up as a result of the in-depth review of all currently available archives and receiving stations' catalogues.

The main features that distinguish the Landsat Pathfinder approach from the FRA 1990 Project's approach can be summarized as follows:

Study area: Major forest areas of humid tropics versus entire tropical coverage.
The Pathfinder programme is concentrated on the large remaining blocks of wet and very moist tropical forests.
The FRA 1990 Project's study area includes all ecological zones down to very dry conditions, as discussed in the present report.

Coverage: Wall-to-wall versus statistical sampling.

Within the study areas the Pathfinder programme is carrying out a complete mapping exercise, limited only by missing data (the areas which resulted to be permanently cloudy or non-recorded). The output of this large scale mapping exercise will find wide use beyond the estimation of tropical deforestation; digital maps of tropical forest cover, with high spatial resolution, will be of great support to national and regional planning.

FRA 1990 coverage entailed a statistical sampling approach of subsequent sample rounds (each covering ten percent of the study area), following the principles of the continuous forest inventory design. Some relevant features of the sampling approach are: (i) the possibility of producing results at various reporting levels, with known confidence limits; (ii) that such results can be released at comparatively short time intervals, thus responding to changing information requirements; and (iii) that, with increasing sampling intensity, such results become progressively more detailed and accurate.

Classification: Coarse versus detailed classification.

The Pathfinder classification includes one forest class: *forest cover*, and the following non-forest classes: *deforestation, non-forest vegetation, water, clouds* and *other.*

The FRA 1990 classification includes ten Main Classes, comprising four forest classes, and 13 additional ones (optional) of greater detail, as presented in Section 2.2. The influence of the land cover classes on the analysis of changes is obvious, as discussed in Section 2.2.1.

Data analysis: Independent digital classification versus interdependent visual interpretation of multi-date satellite data.

The Pathfinder approach consists basically of producing and comparing forest maps based on satellite data sets acquired in three different periods, while the FRA 1990 method is based on the interdependent interpretation of multi-date images with the main focus of achieving the highest possible level of consistency and reliability in the detection of land cover changes.

In considering of the above elements, the Pathfinder approach could be considered as being more extensive while the FRA 1990 approach could be considered intensive.

The first approach aims at the "core" of the tropical deforestation problem, by mapping and quantifying deforestation where the forest is still abundant, but with comparatively coarse thematic resolution. Its major contribution is likely to consist of geographic evidence on: (i) the extent and distribution of humid tropical forests; and (ii) the location of current active deforestation fronts.

The second approach aims at providing a consistent, detailed description and quantification of land cover change processes (not only change in terms of deforestation) for the entire tropical areas; with its detailed description of change processes, FRA 1990 results help one to understand the mechanisms of change, an understanding which is essential to the development of appropriate policies and to the efficacy of remedial action plans.

To date, the main cooperation between the FRA 1990 Project and the Pathfinder Project has consisted in the sharing of Pathfinder's Landsat data and FRA 1990's spatial monitoring results of the Central Africa sub-region.

Chapter VI

What Next?

6.1 SUBSEQUENT SAMPLING CYCLES

This first sample round should be considered as a large pilot study in which all aspects of the continuous global survey have been thoroughly tested and rendered operational. The survey as such has only just been started. The results produced so far meet statistical expectations and, more importantly, are rich in information content which, in describing land cover dynamics, helps one to understand crucial cause-effect mechanisms. These results demonstrate the theoretical correctness of the initial assumptions and have shown that they can withstand the test of implementation at pan-tropical level.

With the experience gained during this first round, both on theoretical and operational issues, the planning and implementation of subsequent survey rounds would appear to constitute a clear and wide path to follow, with very promising and achievable results. The legacy of this first round can be summarized as follows:

- The knowledge gained on the statistical population will serve to optimize stratification and sample allocation which will in turn ensure higher precision at lower cost.
- The network of individuals and institutions with competence on survey methods and procedures will guarantee the improved accuracy of interpretation results.
- The increased knowledge acquired in identifying strengths and weaknesses will allow one to concentrate more attention on those areas of investigation that are known to be more problematic.

In addition to improving the reliability of results and consequently lowering the reporting level from regional and ecological to sub-regional/ecological, further survey rounds will permit the estimation of the changes in the rates of change, i.e., on increase or decrease of deforestation rates. This information will be of paramount interest to national and international policy makers since it would allow a quantitative assessment of the impact of land conservation and development policies, and to highlight the areas exposed to a higher risk of resource depletion.

The proposed continuation of the survey is described in FAO Project Document *GCP/INT/.../G5221, "Programme for Continuous Assessment of Tropical Forest Resources using High Resolution Satellite Data"*, which includes all specifications necessary for conducting three additional survey rounds. The proposal has been submitted to potential donors for funding.

6.2 RECOMMENDED DIRECTIONS FOR FURTHER INVESTIGATION

The results presented here refer to and are based on only the Phase II of the FAO Forest Resources Assessment 1990 Project. Notwithstanding the fact that this was only the first round of a survey designed to be continued and to provide progressively more detailed and reliable results, further potential uses of the present results are numerous. Some of these potential and promising directions for further investigation can be outlined as follows:

- The next most important step, essential to meet fully the purpose of this survey, is **the integration of RS data with FORIS** databases, as discussed above, to complete the two-phase assessment design. This integration will be of mutual benefit, resulting in improved deforestation models, national FORIS statistics and more efficient planning of subsequent survey rounds.

- The consistent use of a standard and rather detailed land cover classification system makes the spatial output of the RS survey (maps of each SU's land cover state and change) a suitable reference for the **calibration** of pan-tropical classification efforts, based on coarse resolution satellite data.

- **Spatial modelling** of forest dynamics. The digital integration of the sampling unit change maps, with their rich information on class transitions, and other GIS layers such as administrative boundaries (and associated socio-economic parameters), road networks, settlements, geo-morphology, etc., will facilitate the development of spatial change models.

Chapter VII

Conclusions

7.1 EVALUATION OF SURVEY DESIGN

Achievements:

- The project's objectives in statistical **precision** expected during the design phase were met or even exceeded, as shown by survey results.

- The survey could be **implemented in toto** (117 out of 117 sampling units), in spite of some difficulties due to non-availability of few images. In addition, all theoretical cornerstones were made **operational**.

- The survey maintained a **decentralized** approach through the active participation of a large number of institutions and individuals, from both developing and industrialized countries, in all stages of the survey, i.e., design, data interpretation and analysis. This cooperative effort ensured an increase of both territorial and theoretical **knowledge**, essential for sound results and effective methods, and permitted widespread **dissemination** of monitoring principles and methodology.

- The remote sensing methodology used, with its **land cover classification** system and **interdependent** procedure of satellite image interpretation, focused particularly on the **consistency** of multi-temporal observation, produced reliable change estimates in the form of change matrices.

- The rich **information** contained in the change matrices led to new **pioneering** methods and areas of investigation such as **change processes** and **flux analyses**, that provide more in-depth perception of forest changes and reveal the "behavior" of a much varied and dynamic landscape.

Shortcomings:

- The whole survey required more **time** than expected and, in particular, **image selection** and **acquisition** have proved to be extremely time consuming.

- As standard products, which represent the processing level within the project's budget, the **images** were often of poor **quality** and consistently manifested relative **geometric distortion**. These constraints have been taken into careful consideration while developing the interpretation and compilation procedures which ensured high consistency and spatial co-registration between interpretation manuscripts of historical and recent images. There is no doubt, however, that good quality images, co-registered geometrically and radiometrically, would facilitate the interdependent interpretation procedure and thus enhance the reliability of the results obtained.

- Owing to funding constraints and access restrictions, **field verification** was carried out only in 15 percent of the sample. In the future, field verification should be effected with greater intensity and should include accuracy assessment techniques for the estimation of measurement errors.

7.2 CONCLUSIONS AND RECOMMENDATIONS

Conclusions

1. The pan-tropical sample survey demonstrates that forest and land use change information can be produced on a global basis in a cost-effective, timely and statistically sound manner. The detailed land cover classification and interdependent image interpretation approach provide consistent information on the change process and, thus, valuable insight into the nature of *man-land* interaction.

2. If continued over time, such surveys would lend factual support to global environmental research and policy making through detailed description of the processes of change, and the quantification of essential parameters, on a reliable basis.

(from FP124, p41: Conclusions)

3. A comparison of the characteristics and results of the FORIS database and the RS survey shows that there is strong complementarity between the two approaches as well as close correlation between their results; these factors call for the integration and continuation of both approaches. The integration of the two data sets will result in: (i) more reliable prediction models and, consequently, more detailed, homogeneous and up-to-date country level data; and (ii) more efficient stratification systems to optimize future sample rounds and expansion of RS results.

4. The de-centralized approach followed during all phases of the survey, from its design to its full implementation, has fostered the creation of a network of institutions and individuals from developing and developed countries. This network of experienced interpreters and advisers, coherently focused on operational forest resource monitoring, has not only contributed to the success of the completed survey but it also constitutes a very important human and institutional resource/reference for future monitoring efforts at both global and national level. The far reaching impact of this cumulative experience should not be considered a small achievement.

Recommendations for future action

1. In view of the information needs of the international community and, in particular, of the studies on global change, it is recommended that the building up of a consistent and reliable time series of observations of forest and land use be continued. Such a time series should include return visits to part of the sampling units included in the first round and an increment in the sample, both in space (new rounds) and in time (three dates in selected sub-samples). Keeping this in view, it is recommended that further statistical designs and analytical systems for a series of transition matrices be developed.

2. It is recommended that the efficiency of the survey design be improved, by:
   - Integrating the sampling frame with existing wall-to-wall spatial and statistical information i.e.:
     (i) forest classification based on NOAA AVHRR at 1 Km resolution; and
     (ii) FORIS statistical and spatial of data base (GIS layers).
   - Focusing on improving change estimates by stratifying on parameters that would reduce the variance of forest area changes, such as demography, economic indicators, infrastructure, etc.

3. it is recommended that in future survey rounds important improvements be made in ensuring satellite image quality and that more resources be invested in field verification and accuracy assessment. Improved spatial and spectral resolution of new and future satellites, associated with multi-temporal processing techniques of co-registration, will guarantee better image quality and, consequently, more accurate interdependent interpretation results. Field verification and accuracy assessment should be carried out more regularly with special attention to areas of complex and poorly discernible land cover[1]

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[1] Provisions for these improvements are already included in the FAO Project Proposal G.5221 "Programme for Continuous Assessment of Tropical Forest Resources using High Resolution Satellite Data".

4. In order to permit the widest possible use and deeper analysis of results obtained, it is recommended that the RS survey be complemented with other data collected at field level:
    - Biomass data in relation to the land cover classes used with high resolution satellite images. This information would allow one to quantify with precision carbon pools and, in particular, release and sequestration related to land cover changes.
    - Biodiversity indicators, similarly related to the adopted land cover classes, that can be used to assess species loss and identify endangered genetic communities.
    - Socio-economic parameters related to the cause-effect mechanisms driving the deforestation process and other land cover changes.

5. In order to respond to the issues mentioned above it is recommended that a multi-phase survey design, aimed at providing reliable data on the state and change of area, biomass and biodiversity for forests and other land cover/uses, be developed and implemented. A three-phase survey design is recommended:

    phase I: **wall-to-wall** information (NOAA AVHRR classifications, FORIS spatial and statistical databases);
    phase II: **remote sensing sample** , based on multi-date Landsat images;
    phase III: **field** inventory sub-sample data.

    Such a comprehensive approach is the only one that would allow the expansion of field information to wall-to-wall pan-tropical and global levels, with known level of reliability and in a timely, cost-effective manner. There is sufficient experience for the first two phases, that can be linked with minor effort, while the development of the field phase, providing ground truth and essential data on biomass, biodiversity and socio-economy, is at present the most challenging element in view of its operational complexity. For this third phase, a series of pilot projects in cooperation with national institutions is recommended, during which flexible and consistent field survey designs will be developed and tested.

6. In view of the positive response to regional workshops and in order to enhance country capacity in producing reliable national change estimates, the further dissemination of sound monitoring procedures, such as the interdependent remote sensing analysis, and the promotion of its implementation to obtain location-specific information to support policy decisions, are recommended. It is also further recommended that at country level the classification system adopted in response to local needs be maintained compatible to the standard global classification system, in order to ensure full contribution of country-level data to the global data base.

Glossary

Land cover classification (see Section 2.2)

Brief definition of the land cover classes used in the pan-tropical survey of forest resources based on high resolution satellite data

Homogeneous Land Cover Classes	average height	canopy coverage	description
Closed Forest	> 5 m	> 40 %	Continuous tree formation of natural origin
Open Forest	> 5 m	10- 40 %	Continuous tree formation of natural origin
Shrubs	1-5 m	> 10 %	Low woody vegetation of natural origin
Other Land Cover		< 10 %	Land with woody vegetation below 10 %
Plantations	> 1 m	(dense)	(synonymous of **Man-made Woody Vegetation)** Forestry or agricultural plantation
Water			Sea, lakes, reservoirs, rivers
Composite Land Cover Classes			
Fragmented Forest	(forest) > 5m	(forest)> 10 %	Mosaic of forest and non-forest with forest fraction between 10 and 70% of total area (estimated average 33%)
Long Fallow	variable	variable	Mosaic of mature forest, secondary forest, various stages of natural regrowth and cultivated areas with cultivated areas covering between 5 and 30 % of total area
Short Fallow	variable	variable	Mosaic of young secondary forest, various stages of natural regrowth and cultivated areas with cultivated areas covering between 30 and 50 % of total area

Other specifications:

- **Scale** : the scale of the interpreted satellite images is 1: 250 000.
- **Minimum mapping unit** = 3 x 3 mm, approximately 50 ha, or 2 mm width for linear features.
- A forest class is considered **continuous** or non fragmented when the non-forest elements (below minimum mapping unit) present in it are less than 30 % of the class.
- A forest class is considered **fragmented** when the non-forest elements (below minimum mapping unit) present in it are more than 30 % of the class and the forest fraction is between 10 and 70 %.
- The **composite classes** (Fragmented Forest, Long Fallow, Short Fallow) are used where individual elements are below minimum mapping unit (< 3 x 3 mm).

Definitions of forest (see Section 2.2.1)

Three different definitions of forest have been adopted in the analysis and presentation of survey results:

F1 = closed forest
F2 = closed + open forest + 2/3 fragmented forest
F3 = closed + open forest + fragmented forest + long fallow

F1 represents forest in the strictest sense, mostly dense, not fragmented nor (heavily) degraded.

F2 is a definition aimed at matching the concept of forest used in FORIS (Forest Resources Information System) by FAO in its periodic assessments based on existing information. According to the FORIS definition the class long fallow is excluded; the reduction factor applied to fragmented forest is due to two factors: (i) forest blocks smaller than 100 hectares are not included, according to FORIS definition, but, in practice, (ii) composite forest/non-forest classes have been considered when more detailed classes were not available, and a certain forest fraction has been estimated and included in FORIS statistics, which is fairly common.

F3 represents forest in its broadest sense, including all types and phases of degradation (but still with the connotation of forest). **This definition of forest, that allows for the most detailed differentiation among changes, has been used in the analysis of change processes presented in the Section 4, "Results and Findings", unless otherwise specified.**

Definitions adopted in the estimation of deforestation and degradation rates (see Section 2.2.1)

- **Gross Deforestation** has been calculated as the sum of all area transitions from natural forest classes (continuous and fragmented) to all other classes.

- **Net Deforestation** has been calculated as the area of Gross Deforestation minus all area transitions into natural forest classes from all other classes.

  In all cases concerning partial deforestation or afforestation, involving the class fragmented forest, the area considered was that of the estimated forest or non-forest fraction.

- **Net Degradation of Natural Forest** has been calculated from the area transitions among natural forest classes, by adding all changes corresponding to *degradation* minus those corresponding to *amelioration.*

- **Balance** between **natural forest** and **man-made woody vegetation** has been calculated as the algebraic sum of the areas, and changes, of natural forest and of man-made woody vegetation at 1980 and 1990.

Other Technical Terms

Biomass (see Section 2.8)

The data sources used for the present study define biomass as: the total above ground biomass density of trees of 10 cm diameter (breast height) or larger, including main stems, branches, bark, twigs, leaves and fruits. In the present study an attempt has been made to estimate, by inference, the biomass of woody vegetation at less than 10 cm diameter, such as that of shrubs and young secondary regrowth.

Co-registration

The spatial, or geometric, co-registration of two satellite images implies that both images are geometrically corrected according to a common projection or that one image is corrected according to the geometric features of he other one which is used as reference; in all cases the co-registration will result in spatial matching and will allow perfect superposition of the two images. The radiometric co-registration of two images consists of common radiometric correction of atmospheric effects and uniform enhancement; images radiometrically co-registered will have similar tonal and chromatic characteristics.

Interdependent interpretation (see Section 2.3)

"Interdependent interpretation" indicates the visual interpretation of two satellite images, acquired at two different dates (in this study some ten years apart), within a single interpretation process. This approach secures the highest level of thematic and spatial consistency between historical and recent image classification. This procedure is the most important element of the methodology since it reduces the error associated to the estimate of changes and make the production of change matrices possible.

Multi-date or **multitemporal**

Multi-date, or multitemporal, satellite data indicates two or more images acquired at different dates and covering the same portion of Earth's surface.

Survey of Tropical Forest Cover and Study of Change Processes

Annexes

ANNEX 1

Abstract of papers, technical reports and other documents produced by, or related to, the Forest Resources Assessment 1990 Project

The findings and main methodological features of the Forest Resources Assessment 1990 Project have been published in the following documents:

Forest Resources Assessment 1990 - Tropical countries. FAO Forestry Paper 112, 1993

Forest Resources Assessment 1990 - Non-tropical developing countries. FAO Technical Report, 1995

Forest Resources Assessment 1990 - Global Synthesis. FAO Forestry Paper 124, 1995

The three publications above summarize the findings of Phase I of the Project, which are reflected in country wise tabulations of forest and forest-related parameters estimated at year 1990, and their changes since year 1980. These documents provide also concise descriptions of the methodologies adopted in both Phase I and Phase II of the Project, some preliminary results of the Remote Sensing Survey (Phase II), still on-going at the time of their publication, and some Special Studies of particular interest.

Forest Resources Assessment 1990 - Tropical forest plantation resources. FAO Forestry Paper 128, 1995. By Devendra Pandey, in the framework of a research programme at the Swedish University of Agricultural Sciences.

This paper provides the best available information on the forestry plantations of 88 tropical countries. It reports areas planted, the purpose and management of the plantations, species composition and survival rates.

The documents listed below represent the main theoretical and technical contribution of both Project staff and external cooperating institution/individuals, to the discussion on, and development of, the methodologies adopted by the Project.

1. PROJECT OVERVIEW - Documents of general nature on the Project

Report on the Expert Consultation (May 1990) FRA 1990 Project

This report contains a review of the Project methodology by the experts and their recommendations, with particular reference to continuous forest inventory design and expansion of the Project activities related to environmental function of forests.

Problems Associated with Estimations of Deforestation and Proposed Methodology for the Project, Background Paper 1 (May 1990) FRA 1990 Project

This short report analyses the problems involved in assessment of deforestation based on existing data and highlights the need for continuous forest monitoring based on remote sensing.

Report of the In-depth Review of the Forest Resources Assessment 1990 Project (April 1992, in English and French) Mission report

This report contains a critical review of the Project's performance covering all objectives, activities and outputs of the Project follow-up.

2. DESIGN I - Assessment based on existing information and mathematical modelling

2.1 Compilation of existing information

Guidelines for Assessment based on Existing Survey Data. (July 1991, in English, French, Spanish); FRA 1990 Project

These guidelines provide data definition and their classification together with instructions for collection and coding of data in a tabular format.

2.2 Data processing

Forest Resources Information System (FORIS) - Concepts and methodology for estimating forest state and change using existing information, (November 1995) by A. Marzoli, FRA 1990 Project

This paper describes in detail the procedures used to produce standardized estimates of forest area at year 1990 and the rate of change between 1981-90, using existing forest inventories/surveys. In particular it contains a description of the modelling techniques used for forest change assessment.

Guide to GIS Databases of the Forest Resources Assessment 1990 Project (June 1991) FRA 1990 Project

The above publications provide an overview of all Project databases, both statistical and spatial.

2.3 Modelling

Estimating and Projecting Forest Area at Global and Local Level: a step forward (November 1990) R. Scotti, FRA 1990 Project

This is an important report providing an in-depth discussion of the Project model.

3. DESIGN II - Remote Sensing based Forest Resources Assessment

3.1 Monitoring methodology based on high resolution satellite data

Methods and Procedures for Assessment of Tropical Forest Area and Change using High Resolution Satellite Data (October 1990), R. Baltaxe and R. Drigo, FRA 1990 Project

This document was the first overview of problems involved in, and suggested approach to, design of the Project activities related to remote sensing.

Monitoring Methodology - Procedure for Interpretation and Compilation of High Resolution Satellite Data for Assessment of Forest Cover State and Change (October 1991) R. Drigo, FRA 1990 Project (in English, French and Spanish)

This is a fundamental document providing detailed guidance on the remote sensing procedure used by the Project.

3.2 The Sample Survey Design and analytical models

Analyses of alternative sample survey designs (February 1991) Dr. R. L. Czaplewski, USDA Forest Service

In this document several alternative methods to estimate tropical forest area and rates of deforestation are reviewed and evaluated, and recommendations are made to optimize the Project's survey design.

The Sample Survey Design (April 1991) FRA 1990 Project

This publication describes the sample survey design based on remote sensing and the estimated magnitude of sampling error.

Evaluation of the Sample Survey Design of the Forest Resources Assessment 1990 Project (March 1992)
Prof. D. R. Pelz, University of Freiburg, Germany

This evaluation of the Project sample survey design was made by IUFRO Group on Biometrics and is very interesting for its in-depth comments.

Recommended Procedures for Analysis of Multi-date Remote Sensing Data of FRA 1990 Project (1992)
Prof. B. Ranneby, Swedish Royal College of Forestry, Sweden

This document presents a first outline statistical formulae for analysis of the Project's remote sensing results, which were finalized in the following paper:

Estimates of Tropical Forest Cover, Deforestation and Change Matrices (SUAS, 1994)
Ms. E. Rovainen, Swedish University of Agricultural Sciences, Sweden.

This paper describes the analytical procedures used to estimate the statistical means and errors of tropical forest cover and deforestation rates, and to standardize the change matrices for the period 1980-1990

Statistical evaluation of FRA 1990 Results (November 1994) Dr. R. L. Czaplewski, USDA Forest Service

This document provides an independent in-depth review and evaluation of the statistical procedures followed by Project

4. SPECIAL STUDIES

4.1 GIS Studies

Forest Biomass Assessment in the Africa Region - Forest Resources Assessment 1990 Project contribution to the African Energy Program (1994), Mr. M. Lorenzini, FRA 1990 Project

This paper describes the methodology adopted by FRA 1990 to evaluate fuelwood production/ consumption balance based on the assessment of natural forest biomass, growing stock annual increment and per capita fuelwood consumption. The assessment is based on spatial analysis of forestry and demographic data on an ecological zone basis. Final results are presented in cartographic and tabular format at national and sub-national level.

Procedures for spatial representation of tabular data (1995), Mr. M. Lorenzini and Mr. A. Marzoli, FRA 1990 Project

This study contains a description of the techniques adopted for the spatial distribution of forest cover data derived from forest inventories. Tabular data, originally associated to large poligons, hence assumed as evenly distributed therein, are reallocated in a more realistic manner, by means of ancillary GIS data. A procedure called "map calibration", combining GIS and multiple regression analysis techniques, allows an improved spatial and statistical distribution of the original data.

4.2 Case studies on forest resources monitoring

Monitoring Tropical Forest Using Spatial Information Techniques (November 1994)
Ms. ir. K. Peirsman and Prof. Dr. ir. R. Goossens, Laboratory of Remote Sensing and Forest Management, University of Gent, Belgium

In this case study, covering one Landsat frame located in the north of Congo, variability in visual interpretation was assessed and visual and digital interpretation techniques were compared; in addition, field validation and accuracy assessment techniques and georeferencing procedures for the FRA 1990 raster maps, were developed.

Forest Resources Assessment in Dry Tropics: a digital alternative for the FAO Forest Resources Assessment 1990 Project (November 1994)
Ms. ir. E. Goossens and Prof. Dr. ir. R. Goossens, Laboratory of Remote Sensing and Forest Management, University of Gent, Belgium

In this case study, based on two Landsat frames located in the north of Cameroon, digital interpretation techniques were compared to the visual approach followed by the FAO FRA 1990 Project.

Analyse et Modélisation de l'Évolution de la Forêt Tropicale Africaine par Télédétection et Systéme d'Information Géograrhique (May 1995)
Mr. M. Lambotte, M. D. Margot and Mr. B. Martens, *Laboratoire de Télédétection et d'Analyse Régionale, Université Catholique de Louvain, Belgique*

In this case study, based on two Landsat frames located in central Cameroon, digital classification and monitoring techniques were carried out and the results used to develop spatial and statistical models of deforestation.

5. REGIONAL WORKSHOPS REPORTS

Tcdc Workshop on Methodology for Deforestation Assessment in South East Asia -
Bangkok 6 - 17 May 1991, FAO Regional Office for Asia and the Pacific (RAPA), Bangkok, (1992). English.

Workshop on Methodology for Deforestation and Forest Degradation Assessment in Africa -
Nairobi 25 November - 13 December 1991 (first regional workshop), FAO Forest Resources Assessment 1990 Project (1992). English.

Taller Latinoamericano sobre Metodología para la Evaluación de la Deforestación y la Degradación Forestal - Ciudad de México, 15 Marzo - 2 Abril 1993,
FAO Forest Resources Assessment 1990 Project (1994). Spanish.

Workshop on Methodology for Deforestation and Forest Degradation Assessment in Africa -
Yaounde 28 February - 18 March 1994 (second regional workshop), FAO Forest Resources Assessment 1990 Project (1994). English and French.

Annex 10 reports, for each regional workshop, a brief summary and abstracts of conclusions and recommendations.

ANNEX 2

Project Team

The list of the Forest Resources Assessment 1990 Project's staff, below, include both Phase I (**FORIS**[1]) and Phase II (**RS**[2]) of the Project. The list of consultants include only those which have contributed to the activities of Phase II.

Project staff

Professional staff	Post	Main activities	Duration (months)
K.D. Singh	Project Coordinator	FORIS / RS	54
R. Drigo	Project Officer, forestry/ remote sensing	RS	48
M. Lorenzini	Project Officer, GIS	FORIS / RS	38
G. Mu'Ammar	GIS/Data processing	FORIS / RS	21
H. Fischer	APO/Project Officer	FORIS	36
A. Hildeman	APO	FORIS / RS	27
S. Vanhaeverbeke	APO in Peru	RS	14
M. Larsson	APO in Thailand	FORIS	30
H. Simons	APO/Project Officer	FORIS / RS	25
D. DeCoursey	APO, GIS	FORIS / RS	24
J. Klaver	Project Officer in Brazil	FORIS / RS	12
P. Howard	Project Officer, GIS	FORIS / RS	9
F. Borry	APO, database management	FORIS	4
D. Piaggesi	Project Officer	FORIS	6
Support staff			
Y. Caccia-Lupu	Administrative Clerk		30
P. Simonetti	Secretary		22
P. Schiro	Secretary		2
R. Nasoni-Cianchi	Data entry clerk/Secretary		12
J. Rechter	Secretary		16

Consultants

(Phase II only)	main contributions	
R. Baltaxe	RS methodology development	4
R. Czaplewski	Survey design	2
A. Marzoli	Database analysis, survey design	6
A. Dell'Agnello	Remote sensing data analysis	9
I. Ambrosini	Remote sensing data analysis	9
C. Fayad	Remote sensing training	1

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[1] Assessment of forest resources based on existing information and development of the Forest Resources Information System (FORIS).

[2] Remote sensing (RS) survey of pan-tropical forest resources based on high resolution satellite data.

Remote Sensing Lead Centers	**Personnel directly involved in satellite data interpretation**
Africa	
Service Permanent d'Inventaire et d'Aménagement Forestiers (SPIAF), Zaire *Department de l'Environnement et Conservation de la Nature*	Mr. Musampa Kamungandu Mr. Bwangoy Bankanza Mr. Shoko Kondjo
Latin America	
Instituto Brasileiro de Meio Ambiente e Recursos Naturais Renováveis (IBAMA), Brazil *Centro de Sensoriamento Remoto*	Mr. C. J. Lorensi Ms. D. Campos Jansen
Secretaria de Agricultura y Recursos Hidraulicos de Mexico (SARH), Mexico	Mr. P. Garcia Mayoral Mr. Alberto Flores
Asia	
Forest Survey of India (FSI), India Vegetation Mapping Unit	Mr. P. C. Joshi Mr. V. K. Bhalla Mr. S. K. Pipara
Royal Forest Department (RFD), Thailand	Mr. Pongpradith Maneesinthu
Forest Inventory and Planning Institute (FIPI), Viet Nam	Mr. Nguyen Manh Cuong
National Forest Inventory (NFI), Indonesia	Mr. Imam Nuryanto Mr. Sudarjio Mr Herman

ANNEX 3

Project Network

Cooperating institutions and individuals:

The Sample Survey Design and Analytical Models

Dr. Ray Czaplewski, USDA Forest Service, USA
Prof. B. Ranneby, Swedish University of Agricultural Sciences (SUAS), Sweden
Ms E. Rovainen, Swedish University of Agricultural Sciences (SUAS), Sweden

The following team of scientists made the review of the Sample Survey Design under the auspices of the International Union of Forestry Research Organizations (IUFRO), Austria:

- Prof. D. R. Pelz, Albert-Ludwigs-Universität, Freiburg, Germany (Coordinator)
- Prof. T. Cunia, State University of New York, USA
- Dr. A. de Gier, International Institute for Aerospace Survey & Earth Sciences, Netherlands
- Dr. S. Poso, University of Helsinki, Finland
- Dr. G. Preto, *Istituto Sperimentale per la Selvicoltura*, Italy
- Prof. B. Ranneby, Swedish University of Agricultural Sciences (SUAS), Sweden
- Prof. K. Rennolls, Thames Polytechnic, United Kingdom
- Dr. P. Schmid-Haas, *Inventaire Forestier National*, Switzerland
- Dr. C.T. Scott, USDA Forest Service, USA

Participants at the Expert Consultation (May 1990):

- Mr. Jan W. Van Roessel, Eros Data Center, U.S.A.
- Mr. Jean Paul Malingreau, Joint Research Center of the EEC, Italy
- Mr. P.R.O. Kio, Forest Research Institute of Nigeria, Nigeria
- Mr. Aarne Nyyssonen, University of Helsinki, Finland
- Mr. H. Kenneweg, *Technische Universität* Berlin, Germany
- Mr. H. Croze, UNEP-GRID, Nairobi
- Mr. Norman Myers, Oxford, U.K. (review of Expert Consultation)
- Mr. Alan Grainger, University of Salford, Salford, U.K.
- Mr. George M. Woodwell, The Woods Hole Research Center, U.S.A.
- Mr. Klankamsorn Boonchana, Royal Forestry Department, Thailand
- Mr. L. Sayn Wittgenstein, Canada Center for Remote Sensing, Canada
- Mr. Vernon J. La Bau, Pacific Northwest Experiment Station, Alaska, USA

Members of the In-depth Review Mission (April 1992):

- Mr. Derk de Groot, Ministry of Agriculture, Nature Management & Fisheries, the Netherlands
- Dr. Paul C. Van Deusen, Southern Forest Experiment Station, U.S.A.
- Dr. Ashbindu Singh, United Nations Environment Programme - GRID, Kenya
- Dr. Nils Erik Nilsson, National Board of Forestry, Sweden
- Dr. Michel Deshayes, *Ecole Nationale du Génie Rural, des Eaux et des Forêts*, France
- Mr. Paul Howard (rapporteur), USDA Forest Service, U.S.A.

Monitoring methodology

Mr. R. Baltaxe (retired FAO officer)
Mr. L. Björk, University of Agricultural Sciences, Umeå, Sweden) Pilot study
Mr. H. Österlund, Swedish Space Corporation, Sweden)

Prof. Dr. ir. R. Goossens, Faculty of Agricultural and Applied Biological Sciences, University of Gent, Belgium
Ms. ir. E. Goossens = =
Ms. ir. K. Peirsman = =
Mr. M. Lambotte, *Université Catholique de Louvain*, Belgium

Processing and supplying of remote sensing data

Mr. C. Justice, NASA Goddard Space Flight Center, University of Maryland, USA
Mr. W. T. Lawrence, NASA/Goddard Space Flight Center, University of Maryland, USA
Dr. Suvit Vibulsresth, National Research Council of Thailand (NRCT) (contribution of TM data free of charge)

Earth Observation Satellite Co. (EOSAT), USA)
USGS EROS Data Center, USA)
National Remote Sensing Agency (NRSA), India) Delivery of
National Receiving Station, Indonesia) satellite imagery
Instituto Nacional de Pesquisas Espaciais (INPE), Brazil)

Analysis of remote sensing data at sample locations

The following institutions and individuals have directly contributed to the interpretation of satellite data under various forms of agreement. Their data analysis work has complemented that carried out at Lead Centers (listed in Annex 2) and at four regional workshops.

Istituto Agronomico per l'Oltremare (Overseas Agronomic Institute), (IAO), Ministry of Foreign Affairs, Italy

Messrs Paolo Sarfatti and Luca Ongaro, IAO Officers.	(Supervision)
Ms Angela Dell'Agnello, Forestry/Remote Sensing Expert	(Data analysis)
Ms Ilaria Ambrosini, Forestry/Remote Sensing Expert	"

Javier Anduaga, *Ministerio de Agricultura, Oficina General de Planificación Agraria* (OPA), Peru
Homero Chaccha Córdova, *Instituto Nacional de Recursos Naturales* (INRENA), Peru
Leonardo Lugo and Paulino Ruíz Mendoza, *Servicio Forestal Venezolano* (SEFORVEN), Venezuela
Gerónimo Grimaldez, *Centro de Desarrollo Forestal, Ministerio de Asuntos Campesinos y Agropecuarios*, Bolivia
Raúl Lara Rico, *Centro de Investigaciones de la Capacidad de Uso Mayor de la Tierra* (CUMAT), Bolivia

ANNEX 4
(Section 2.1.1)

Distribution of land area by stratum and sub-region

Distribution of land area (within Landsat frames) by stratum and sub-region
Land area in million hectares derived from project's GIS

	1 Forest	2 Woodland	3 Tree savanna	Total surveyed	4 & 5 Non-forest or forest<10%	6 Land area <1M ha	Total not surveyed	Grand Total
East-Sahelian Africa	91.5	0.0	136.9	228.4	290.0	5.8	295.8	524.2
West-Sahelian and West Afr.	60.0	51.0	137.5	248.5	491.3	14.3	505.5	754.1
Central Africa	284.8	52.2	57.6	394.6	16.4	0.2	16.6	411.1
Tropical Southern Africa	0.0	245.6	106.9	352.5	212.9	10.8	223.7	576.2
Sub-total Africa[1]	**436.2**	**348.8**	**439.0**	**1224.0**	**1010.6**	**31.0**	**1041.6**	**2265.6**

	1 Forest cover >70%	2 Forest cover 40-70%	3 Forest cover 10-40%	Total surveyed	4 & 5 Non-forest or forest<10%	6 Land area <1M ha	Total not surveyed	Grand Total
Mexico and Central America	28.7	69.9	51.3	149.9	72.8	18.0	90.8	240.7
Tropical South America	233.9	108.9	110.3	453.2	134.4	11.3	145.7	598.8
Brazil	413.7	92.0	124.8	630.5	207.1	11.3	218.4	848.9
Sub-total Latin America[2]	**676.3**	**270.9**	**286.4**	**1233.6**	**414.3**	**40.5**	**454.8**	**1688.4**
South Asia	0.0	50.0	151.1	201.1	222.0	14.9	236.9	438.0
Continental South-East Asia	0.0	91.9	94.3	186.2	1.1	14.5	15.7	201.9
Insular South-East Asia	114.7	53.4	55.1	223.2	7.2	58.5	65.7	288.8
Sub-total Asia	**114.7**	**195.2**	**300.6**	**610.5**	**230.2**	**88.0**	**318.2**	**928.7**
GRAND TOTAL	**1227.2**	**814.9**	**1026.0**	**3068.0**	**1655.1**	**159.6**	**1814.7**	**4882.7**

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[1] Excluded Madagascar

[2] Excluded Caribbean islands

ANNEX 5
(Section 2.2)

Land Cover Classification

Introduction

The objective in designing the present classification has been to provide a framework which will allow the segregation of all the types of woody vegetation cover encountered on high resolution satellite data (HRSD) of the tropics into the classes of interest to the Forest Resources Assessment 1990 Project.

The classification has three main characteristics:

- a hierarchical structure to permit the unambiguous aggregation of the classes at each level to the next level or levels.

- a simple dichotomy at each level, based on criteria usually detectable on HRSD, or readily inferred, to facilitate the interpreters's decision at that level and about whether it would be possible to proceed to the next lower (more detailed) level.

- the inclusion of all the classes of interest to the assessment of state and change of forest cover in a form obtainable from HRSD.

The classification system here adopted (shown in Section 2.2 of the main text) is composed of three main parts. These parts are progressively followed during the interpretation of the "1990" and "1980" satellite images.

Classification levels

The classification has been divided into two levels in order to ensure a minimum level of global correspondence and to concentrate the monitoring exercise at a simpler more reliable classification level. That is to say that, for the purpose of global monitoring, it is not allowed to group classes of the main level during the interpretation and analysis.

These two levels are represented by the Main Classes and the Additional Classes. The Main Classes (10 in total) identify the minimum common standard for Sub-regional, Regional and Global reporting of results. The Change Matrices are produced as a standard output for the Main Classes only.

The Additional Classes represent further subdivisions of the Main Classes. These Additional Classes will be used only where their delineation is considered reliable.

The decision to use Additional or Main level of classification will be documented for each class of each image on the Sampling Unit Description - ID Form and respected throughout the interpretation of that image. This means that the Additional Classes and their parent Main Class can never coexist on the same interpretation overlay.

PART 1. PRELIMINARY IMAGE INTERPRETATION CLASSES

The image is divided into three main classes:

- OTHER NON-INTERPRETED
- WATER
- LAND

OTHER NON-INTERPRETED includes all portions of the image that are outside the study area (parts of image that fall outside the region or sub-region of interest) or that cannot be reliably interpreted due to presence of burnt grass (in woodland areas), clouds or dense atmospheric haze and shadows. Under the main class are' found the additional classes *BURNT WOODLAND, CLOUDS-CLOUDS SHADOWS, MOUNTAIN SHADOWS and OUTSIDE STUDY AREA.*

The additional class *BURNT WOODLAND* refers to those areas, such as Myombo Woodlands in Africa, Dry Dypterocarp Forests in Asia and Cerrado formations in Latin America where the recurrent fires destroy only (or mainly) the grass layer present under the tree cover. In these areas the black patches left by the crossing of fire would not represent a loss of woody vegetation but rather "hide" the area and prevent the interpretation.

In other conditions, where the fires are known to destroy the forest completely or to follow the clearing of the forest , the class to be used for burnt areas is "Other land cover", to indicate the loss of woody vegetation cover.

Therefore, it is important to classify the burnt areas with maximum care, taking into account the types of forest and land use of the area of study.

> *WATER* includes sea and major inland water bodies. Minor water bodies and river courses are not separated but are included in the broad class "other land cover".
>
> *LAND* includes all the remaining part of the image. This class is subsequently divided according to the presence or absence of (significant) *WOODY VEGETATION COVER*. 10 % is here used as the lower cover limit. The remaining land area falls under the class *OTHER LAND COVER*.

The class *WOODY VEGETATION COVER* is then further divided according to its origin into *NATURAL* and *MAN-MADE*. This division, which is based on characters that are partly physiognomic and partly contextual, is dictated by the need to separate, as far as possible, these two broad categories for separate analysis and monitoring studies. Their separation will no doubt be approximate in some cases, especially when poor quality plantations are intermixed with natural vegetation and when there is little background information available. An attempt of separation is, in all cases, considered important.

The *MAN-MADE WOODY VEGETATION* cover type includes a wide range of vegetation and land use types. For the purpose of the present study the important distinction that needs to be made is between forest plantations and agricultural wooded areas.

> *FOREST PLANTATIONS* will be delineated within the class Man-made Woody Vegetation Cover as visible on the HRSD and with the support of auxiliary data. Plantation area is needed as broad statistical input without the need for detailed description like species composition, age, etc.
>
> The remaining part of the class Man-made Vegetation Cover after the separation of Forest Plantations will be constituted by *AGRICULTURAL PLANTATIONS* and homestead gardens. This class will include, without further separation, all formations such as tea gardens, oil-palm, coconut, rubber plantations, etc. and the homestead mixture of trees and shrubs.

It is normally difficult to separate forest plantations from agricultural plantation based only on the spectral signature or the texture of the forest cover. It is therefor necessary to make a contextual interpretation with strong support of all available auxiliary information, for example plantation and landuse maps.

The *NATURAL WOODY VEGETATION COVER* classification is outlined under Part 2.

PART 2. CLASSIFICATION OF NATURAL WOODY VEGETATION COVER

The word "cover" is used deliberately to avoid confusion with vegetation types or formations, which have floristic connotations. This is because for a global assessment they are not of primary importance; the concern is less with local management than with estimates of global forest cover and its dynamics of biomass for global modelling and implications for species diversity, etc. Equally relevant is the fact that for a survey based on satellite data with, at this stage, very restricted scope for rigorous accuracy assessment, interpretation of floristic aspects would be of low and unequal reliability.

The classification therefore distinguishes types of woody vegetation cover primarily on the physiognomic characteristics - density or crown cover, spatial distribution - which are those most readily observed on HRSD.

Height is used for the distinction between *FOREST* (trees) and *SHRUBS*, which constitutes the first dichotomy of the classification. While the need to differentiate between tree and shrub formations is obviously important, in practice these two categories are not always readily distinguished on satellite data. More than height, which cannot be accurately perceived on the HRSD used for the study, spectral signature and background data on local ecology guide the distinction between these two classes.

The *CONTINUOUS - FRAGMENTED* dichotomy under *FOREST* refers to the spatial distribution of the class *FOREST* and other classes. Whenever the forest units can be individually delineated and therefore separated from the surrounding classes they will belong to the *CONTINUOUS* class.

Where the forest units are intimately intermixed with other cover types to a level that they cannot be individually separated, then the mixture of the two (or more) cover types will be classified as *FRAGMENTED* and subsequently divided according to the estimated proportions of the forest type within the class.

Quantitative criteria

Quantitative classification criteria for use with the interpretation of HRSD can only be indicative as neither height nor crown cover can be seen or measured directly. For this reason, also, limits are set as: 10-40% and 40-70%, for example, rather than 10-40% and 41-70%.

The lower limit of 10% woody vegetation cover for 'Forest' and related formations is that adopted for the periodic FAO forest assessments and is in conformity with the UNESCO International Classification of Vegetation. Except in a few special cases, it is unlikely that 10% crown cover is detectable on HRSD. The detectable lower limit for this will vary with the type of woody vegetation and with the nature and condition of the associated ground cover.

The threshold of 5 m in height to differentiate trees and shrubs is also that adopted for the periodic FAO forest assessments. On HRSD it is usually possible to distinguish between a tall tree canopy and cover which consists of much shorter woody vegetation, especially when these occur with close spatial relation. However, the reliability of this distinction is variable and it should be confirmed from other sources whenever possible.

The 40% crown cover threshold corresponds to the lower limit for woodland in the UNESCO and other classifications with the purpose to distinguish the latter from the so-called mixed formations of grassland with trees - tree savanna, cerrado etc. In the present study the same crown cover threshold is used to separate open canopy and closed canopy forests.

The class *CONTINUOUS* is divided into the two main interpretation classes *OPEN FOREST* and *CLOSED CANOPY FOREST* based on crown cover; 10 - 40% and 40 - 100% respectively.

The very broad range of 40-100% crown cover has been further divided, arbitrarily, into two additional classes *DENSE FOREST (Crown cover 40-70%)* and *DENSE FOREST (Crown cover 70-100%)*. The 70% threshold has been introduced to account for a wider range of situations in which the division between closed and open forest with a 40% crown cover threshold is not meaningful; tropical rain forest with 60% crown cover may well be a disturbed, degraded formation, while in a drier eco-floristic zone the same crown cover may well represent a stable undisturbed formation.

For the class *FRAGMENTED* forest (mosaic of forest and shrubs or other land cover) the limits have been set to correspond to those of open canopy forest, *FOREST FRACTION 40-70%*, and Dense forest (c.c. 40 - 70%), *FOREST FRACTION 40-70%*, to facilitate the aggregation of classes of forest cover. For the class shrubs the threshold has been set arbitrarily at 40% crown cover (for consistency with the other limits used) to yield additional information when it can be interpreted from the satellite data.

PART 3. AGRICULTURAL IMPACT

Agricultural impact within continuous forest areas can be detected on HRSD by the presence of small cultivated patches (below the delineation limit) surrounded by equally small patches of natural vegetation at various stages of regrowth and areas of mature, more or less disturbed forest. This structure commonly indicates the on-going practice of shifting cultivation.

From a strictly physiognomic point of view such a forest area would still maintain all the characters of 'continuous forest' with a certain crown cover; although degraded, the forest affected by shifting cultivation could maintain, in some cases, the same crown cover as the surrounding unaffected forest.

However, in spite of this, it is important that such situations are detected and monitored in view of the important role that these practices play in the degradation process of the natural resources.

The objective of the interpretation in this case is to outline the portions of forest that appear to be affected by shifting cultivation as forest with *AGRICULTURAL IMPACT* In practice this would mean to outline, as a sort of mosaic class, the areas under actual cultivation (cleared) and the areas at various stages of regrowth that represent the areas cultivated and subsequently abandoned in a more or less recent past.

An attempt is also made to further divide the class Agricultural Impact two additional classes, named *SHORT FALLOW* and *LONG FALLOW*, on the basis of the estimated intensity of the agricultural practices.

The intensity of the shifting cultivation is usually estimated by a ratio given by the length of time for which a given land unit is cultivated over the length of time for which it is left fallow.

FAO (1984) uses Ruthenberg's R factor to classify shifting cultivation in Africa in the following way:

$$R = C \times 100 / (C + F)$$

where: C = cropping period; F = fallow period.

In that study a value of R greater or equal to 33 is considered the 'short fallow' type and an R value smaller than 33 is classed as the 'long fallow' type.

The time factor is obviously undetectable in a study based on satellite data. Nevertheless, a similar estimate is possible on the basis of the spatial proportion and distribution of the patches under actual cultivation and the patches under fallow period. This is based on the assumption that the cropping period, whatever length this could have, is constant in time.

An area with Agricultural Impact-Present can be further divided using a visual estimation of the proportion of the cropping area as follows:

$$\text{Cropping area} * 100 / (\text{Cropping} + \text{Fallow area})$$

The area for which the resulting ratio is estimated as equal or over 33 (over 1/3 of the area) is classified as Short Fallow, and the area for which the ratio is estimated as less than 33 (less than 1/3 of the area) is classified as Long Fallow.

INTERPRETATION KEY

```
 (total image)
  visible --- No --- OTHER NON INTERPRETED
                              |
                     outside image/ --- No -- burnt in (1) -- no -- clouds, cloud -- no -- MOUNTAIN
       Yes            sub-region              woodland area          shadow                SHADOW
                                                    |                   |
                                                   yes                 yes
                                                    |                   |
                                            BURNT WOODLAND (1)     CLOUDS, CLOUD
                                                                     SHADOWS

                              Yes ------------- OUTSIDE STUDY AREA


       land ---------- No ------ WATER
        |
        Yes
        |
woody veg.cover >10% -- No ------ OTHER LAND COVER
                                       |
                                  rocks, snow -------- No --- OTHER LAND COVER
        Yes

                                       Yes ------------------ SNOWCAPS, ROCKY AREAS


     natural --------- No ------ MAN-MADE WOODY VEG.COVER
                                       |
                                forestry purpose(2) -- No --- AGRICULTURAL PLANTATION
        Yes                            |
                                       |
                                       Yes ------------------ FORESTRY PLANTATIONS

   height > 5 m ------ No ------- SHRUBS
                                       |
                              crown cover >40% -------- No ---- SPARSE SHRUBS
        Yes                                                     (crown cover 10-40%)

                                        Yes ------------------  DENSE SHRUBS
                                                                (cc >40%)

    continuous ------- No ------ FRAGMENTED
        |                              |
        |                     forest fraction >40% ---- Yes --- FOREST FRACTION 40 - 70%
        Yes                            |
                                       |
                                       No ------------------- FOREST FRACTION 10 - 40%


  agricult. impact ---- Yes --- cropping area >33% -- Yes -- SHORT FALLOW
        |                              |
        |                              |
        No                             No ------------------- LONG FALLOW
        |
        |
  crown cover >40% ---- No ------ OPEN CANOPY FOREST  (cc 10-40%)
        |
        |
        Yes -------------------- CLOSED CANOPY FOREST (cc >40%)
                                       |
                                crown cover >70% ----- No --- DENSE FOREST (cc 40-70%)
                                       |
                                       |
                                       Yes ------------------ DENSE FOREST (cc >70%)
```

---

(1) Burnt grass layer in woodland areas "hide" the tree cover preventing interpretation. Burnt forest (not grass) should be classified as "Other land cover".

(2) Distinction based on auxiliary data.

Note: Main level classes are bolded

ANNEX 6
(Section 2.3)

Evaluation of Interpretation Procedures

With the purpose of identifying the most suitable visual interpretation procedure for the pan-tropical forest cover survey, three different approaches have been tested for a selected site in Zaire and the results compared . The results of this study are described in the Project Paper: "Interpretation of High Resolution Satellite Data and Compilation of Results for Forest Cover State and Change Assessment; Test Site: Zaire" (R. Drigo, 1991) and summarized below:

Given that interpretation of the "1990" image has already been finalized, the three tested procedures for change estimation can be described briefly as follows:

Procedure 1. "Change detection"

Interpret only the changes by superimposing the "1990" interpretation overlay on the "1980" image and subsequently marking only the areas that have changed from one class to another. This approach produces an overlay where only the changes are delineated.

Procedure 2. "Sideways interpretation of the '1980' image"

Carry out the interpretation of the "1980" scene separately with only "sideways" comparison of the previously interpreted "1990" image. This approach produces a complete, separate interpretation of the "1980" data.

Procedure 3. "Interdependent Interpretation; Complete interpretation of the '1980' image with superimposed '1990' delineation"

This procedure represents a combination of the two systems above. The interpretation of the "1980" image is carried out completely (over the common area) with continuous reference to the "1990" interpretation while it is superimposed on the "1980" image. This approach produces a complete interpretation of the "1980" image, with both changed and unchanged classes.

The results of the test study indicate clearly that Procedure 3 is the most suitable for a thorough and consistent estimation of.forest cover changes. It is therefore suggested that Procedure 3 be followed based on the evaluation below.

Compared to Procedure 1, Procedure 3 shows a higher sensitivity in the detection of changes. Procedure 1 identifies changes through a visual scanning process that is liable to perceive only changes of high magnitude and may lead, especially on images with a highly fragmented pattern, to a systematic underestimation of changes. The higher sensitivity of Procedure 3 is due to the fact that, by thoroughly delineating the "1980" image with the "1990" overlay superimposed, the interpreter is obliged to confirm or change all the lines of the previous interpretation, thus reducing the risk of missing minor changes that a scanning process might not reveal.

Procedure 2, with only background or sideways relation to the previous interpretation, is prone to introducing apparent changes due to the subjective delineation of unchanged boundaries. The risk of apparent changes due to subjective delineation is inversely proportional to the tonal contrast between adjacent classes. Boundaries between forest classes of varying densities or between forest and shifting cultivation, etc. are usually highly subjective and therefore their changes as estimated by Procedure 2 will be very unreliable. Procedure 3 reduces the risk of apparent changes to a minimum since the new delineation is changed only if justified clearly by differences between the two images.

Subjectivity in class delineation is unavoidable in visual interpretation. Procedure 3 offers the possibility of eliminating the effects that the subjectivity of the second interpretation could bring into the estimation of changes.

The “superimposed”, interdependent interpretation of the two images has also a positive effect on the overall class delineation accuracy. In addition to the detection of changes, Procedure 3 allows the interpreter to use a second layer of information over the common area that may help to improve the interpretation carried out on the first image. It is envisaged that the interpreter, while interpreting the second image, will need to go back to the previous overlay (and image) to introduce some changes to classes of uncertain delineation.

This "maturing" process is possible only if the two interpretations are carried out with constant, mutual reference.

ANNEX 7
(Section 2.5)

ANALYSIS AND STANDARDIZATION OF TRANSITION MATRICES

[From Project paper "Estimates of Tropical Forest Cover Cover, Deforestation and Matrices of Change"
(E. Rovainen, PhD thesis, Swedish University of Agricultural Sciences (SUAS), 1994)]

[In this section, a method will be presented for standardizing the observed land cover class-to-class changes of the individual Sampling Units (SU), which have varying time references, to the standard ten-year period 1980-1990.]

1 Background

(...) Let A be the nine-by-nine matrix obtained from the satellite photo-interpretation for the common area of the recent and historical satellite image :

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{19} \\ a_{21} & a_{22} & \cdots & a_{29} \\ & & & \vdots \\ a_{91} & a_{92} & \cdots & a_{99} \end{bmatrix} \tag{4.1}$$

Then a_{mn} is the area belonging to class m at occasion 1 and class n at occasion 2.

These transition matrices, which exist for each sampling unit, can be used to obtain estimates for arbitrary regions. To make these regional estimates possible, each transition matrix has to be transformed to a tenth-year transition matrix. This was accomplished in the FRA90 project by first making the transition matrix annual using a method called diagonalization.

2 Diagonalization

Since the photo-interpreted area varies between each pair of satellite images, the transition data have to be changed to probabilities. Recall that, a_{mn} is the area belonging to class m at occasion 1 and class n at occasion 2. Let a dot-index denote the sum over that index. Then

$$a_{nm} = \sum_{n=1}^{9} a_{nm} \tag{4.2}$$

is the total area belonging to class m at occasion 1.

The *probability* of belonging to class m at occasion 1 and class n at occasion 2 is

$$r_{mn} = \frac{a_{mn}}{a_{m}}. \tag{4.3}$$

Assume t years between occasion 1 and occasion 2. Then the probability transition matrix is denoted by

$$R^{(t)} = \left[r_{mn}\right], \tag{4.4}$$

which is known from the photo-interpretation. We want to obtain the *annual* probability matrix, denoted by $P=[p_{mn}]$. Here p_{mn} denotes the probability of changing from class m to class n during one year.

The probability transitions can be regarded as a stochastic process. An assumption made here is that the transition probabilities are time-homogenous, thereby fulfilling the Markov property. This means that, given the class at the latest time, the probability to go to class k (for all k) is independent of the classes at earlier time points. The assumption is reasonable at least for short time intervals, and it implies that

$$P \cdot P \cdot \ldots \cdot P = P^t = R^{(t)}.$$

From this relation the annual probabilities p_{mn} can be calculated using diagonalization [Çinlar (1975)].

The idea behind diagonalization is to split (diagonalize) P in the following way:

$$P = B \cdot D \cdot B^{-1}$$

where D is a diagonal matrix. Matrix D has the eigenvalues of P in the diagonal.

$$D = \begin{pmatrix} \lambda_1 & 0 & \ldots & 0 \\ 0 & \lambda_2 & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & \ldots & \lambda_n \end{pmatrix} \tag{4.6}$$

The columns in B consist of the corresponding eigenvectors.

According to calculation rules for matrices, it holds that

$$D^t = \begin{pmatrix} \lambda_1^t & 0 & \ldots & 0 \\ 0 & \lambda_2^t & & 0 \\ & & & \\ 0 & 0 & \ldots & \lambda_9^t \end{pmatrix} \tag{4.7}$$

and, independently of how B appears, that

$$B^{-1} \cdot B = I = \begin{pmatrix} 1 & 0 & \ldots & 0 \\ 0 & 1 & & 0 \\ & & & \\ 0 & 0 & & 1 \end{pmatrix}$$

If $P = B \cdot D \cdot B^{-1}$, then

$$P \cdot P = B \cdot D \cdot B^{-1} \cdot B \cdot D \cdot B^{-1} = B \cdot D \cdot I \cdot D \cdot B^{-1} = B \cdot D \cdot D \cdot B^{-1} = B \cdot D^2 \cdot B^{-1}$$

and by induction

$$P^t = B \cdot D^t \cdot B^{-1},\ t = 1,2, \ldots . \tag{4.8}$$

Thus from the known $R^{(t)}$ the annual probability matrix P can be obtained as

$$P = B \cdot \begin{bmatrix} \sqrt{\lambda_1} & 0 & \dots & 0 \\ 0 & \sqrt{\lambda_2} & & 0 \\ \vdots & & \ddots & \\ 0 & 0 & & \sqrt{\lambda_9} \end{bmatrix} \cdot B^{-1}. \tag{4.9}$$

Note that the eigenvalues in D may be complex. It is possible to diagonalize $R^{(t)}$ if the eigenvectors of $R^{(t)}$ are linearly independent. Unfortunately the annual probability matrix P obtained by this method is not necessarily unique.

From the annual probability matrices it is possible to retrieve the areas in different classes for 1980. Let $\underline{a}=[a_1,a_2, \dots, a_9]$ be the areas in the different classes at time T (e.g. the first satellite acquisition) and $\underline{b}=[b_1,b_2, \dots, b_9]$ the corresponding areas at time (T + 1). Then the following holds:

$$\underline{b} = \underline{a} \cdot P \text{, and} \tag{4.10}$$

$$\underline{a} = \underline{b} \cdot P^{-1}. \tag{4.11}$$

Example

If the first satellite image is obtained in 1978, then $\underline{a}$ is known from the photo-interpretation and the areas in the different classes in 1980 are obtained by using (4.10) twice, i.e.

$$\underline{b}(80) = \underline{a} \cdot P \cdot P = \underline{a} \cdot P^2.$$

If the first satellite image is from 1981, then $\underline{b}$ is known from the interpretation and the areas in the different classes in 1980 are given by relation (4.11), i.e.

$$\underline{a}(80) = \underline{b} \cdot P^{-1}$$

Thus it is possible to obtain the interpreted areas in different cover classes for year 1980. Thus estimation of transition matrices and areas for different cover classes are possible using this approach for any arbitrary region in any time period.

A ten year probability transition matrix can be calculated for all images. Assume that areas for different cover classes are photo-interpreted for all first occasion (i.e., near to the year 1980) satellite images for the sample units selected in the sample. Denote the 10 year transition matrix by Q, where

$$Q = P \cdot P \cdot \dots \cdot P = P^{10}$$

For image k, the 1980s areas are denoted by $a_m(k)$, $m = 1, \dots, 9$. The area transition matrix for 1980-1990 is obtained as

$$A(k) = [a_{mn}(k)],$$

where

$$a_{mn}(k) = q_{mn}(k) \cdot a_m(k) \tag{4.12}$$

For the region, the ten year probability transition matrix $\hat{Q} = \left[\hat{q}_{mn}\right]$ is then estimated as:

$$\hat{q}_{mn} = \frac{\sum_{k} a_{mn}(k)}{\sum a_{m.}(k)} \qquad (4.13)$$

Practical problems

For the first satellite image acquisition, there is occasionally no area in one or several cover classes. For these classes, it is not possible to calculate the transition probabilities. One way to solve this problem is to let the probability of staying in the same class (i.e. r_{mn}) be equal to one. This implies that all the areas coming from the other cover classes will stay in this class. One reason to make this assumption is that this class will not affect the estimation of transition probabilities for other classes when computing P.

This procedure was considered acceptable when calculating transition probabilities and areas for 1980 and 1990. However for the purpose making forecasts for long time periods, this means that the area will crease in the class (since no area disappears from it).

When making long term forecasts, a better solution is to take the average of the transition probabilities in the class for all matrices in the sample, and then use this average probability in the R-matrix.

References

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[Cochran (1977)] Cochran, W.G (1977). Sampling Techniques. *John Wiley & Sons, Inc.*

[Çinlar (1975)] Çinlar, E. (1975). Introduction to stochastic processes. *Prentice-Hall, Inc.*

ANNEX 8
(Section 2.8)

Indicative Biomass Gradients in Class-to-Class Relations

Gradients are expressed in tonnes per hectares, as absolute values

Ecological zone: **WET AND VERY MOIST**

Cover Classes			**Closed Forest**	**Open Forest**	**Long Fallow**	**Fragmented Forest**[1]	**Shrub**	**Short Fallow**	**Other Land Cover**	**Water**	**Plantation**
						33					
		tonnes/ha	300	100	130	99	50	40	10	0	150
Closed Forest		300		**200**	**170**	**201**	**250**	**260**	**290**	**300**	**150**
Open Forest		100	**200**		**30**	**67**	**50**	**60**	**90**	**100**	**50**
Long Fallow		130	**170**	**30**		**31**	**80**	**90**	**120**	**130**	**20**
Fragm.Forest [1]	33	99	**201**	**67**	**31**		**49**	**59**	**89**	**99**	**51**
Shrubs		50	**250**	**50**	**80**	**49**		**10**	**40**	**50**	**100**
Short Fallow		40	**260**	**60**	**90**	**59**	**10**		**30**	**40**	**110**
Other Land Cover		10	**290**	**90**	**120**	**89**	**40**	**30**		**10**	**140**
Water		0	**300**	**100**	**130**	**99**	**50**	**40**	**10**		**150**
Plantation		150	**150**	**50**	**20**	**51**	**100**	**110**	**140**	**10**	

Ecological zone: **MOIST WITH SHORT AND LONG DRY SEASON**

Cover Classes			**Closed Forest**	**Open Forest**	**Long Fallow**	**Fragmented Forest**[1]	**Shrub**	**Short Fallow**	**Other Land Cover**	**Water**	**Plantation**
						26.4					
		tonnes/ha	200	80	70	66	30	20	5	0	100
Closed Forest		200		**120**	**130**	**134**	**170**	**180**	**195**	**200**	**100**
Open Forest		80	**120**		**10**	**53.6**	**50**	**60**	**75**	**80**	**20**
Long Fallow		70	**130**	**10**		**4**	**40**	**50**	**65**	**70**	**30**
Fragm.Forest [1]	26.4	66	**134**	**53.6**	**4**		**36**	**46**	**61**	**66**	**34**
Shrubs		30	**170**	**50**	**40**	**36**		**10**	**25**	**30**	**70**
Short Fallow		20	**180**	**60**	**50**	**46**	**10**		**15**	**20**	**80**
Other Land Cover		5	**195**	**75**	**65**	**61**	**25**	**15**		**5**	**95**
Water		0	**200**	**80**	**70**	**66**	**30**	**20**	**5**		**100**
Plantation		100	**100**	**20**	**30**	**34**	**70**	**80**	**95**	**100**	

Ecological zone: **SUB-DRY TO VERY DRY**

Cover Classes			**Closed Forest**	**Open Forest**	**Long Fallow**	**Fragmented Forest**[1]	**Shrub**	**Short Fallow**	**Other Land Cover**	**Water**	**Plantation**
						19.8					
		tonnes/ha	120	60	50	39.6	15	10	3	0	100
Closed Forest		120		**60**	**70**	**80.4**	**105**	**110**	**117**	**120**	**20**
Open Forest		60	**60**		**10**	**20.4**	**45**	**50**	**57**	**60**	**40**
Long Fallow		50	**70**	**10**		**10.4**	**35**	**40**	**47**	**50**	**50**
Fragm.Forest [1]	19.8	39.6	**80.4**	**20.4**	**10.4**		**24.6**	**29.6**	**36.6**	**39.6**	**60.4**
Shrubs		15	**105**	**45**	**35**	**24.6**		**5**	**12**	**15**	**85**
Short Fallow		10	**110**	**50**	**40**	**29.6**	**5**		**7**	**10**	**90**
Other Land Cover		3	**117**	**57**	**47**	**36.6**	**12**	**7**		**3**	**97**
Water		0	**120**	**60**	**50**	**39.6**	**15**	**10**	**3**		**100**
Plantation		100	**20**	**40**	**50**	**60.4**	**85**	**90**	**97**	**100**	

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[1] Biomass of *fragmented forest*, estimated as 33 % of that of *continuous* forest, depends from the forest class of origin (or destination): the lower values refer to *open forest* while the higher values refer to *closed forest*.

ANNEX 9

(Section 3.1)

List of Sampling Units and Satellite Images

SUBREGION and Location	Sample Code	Acquisition	Path	Row	Overlay of hist. image	Sensor (blanck =MSS)	Sub-Code	DATE d/m/y	DATE2 d/m/y	Supplier
SR 14 - West and West Sahelian Africa										
Nigeria-N	1408	Recent	186	052	0			6/1/87		Eosat
Nigeria-N		Historic	200	052	85	BW		3/12/75		Edc
Nigeria-C	1410	Recent	187	054	0			12/12/86		Eosat
Nigeria-C		Historic	201	054	90			9/1/76		Edc
Nigeria-N	1407	Recent	188	052	0			17/11/86		Eosat
Nigeria-N		Historic	202	052	100			19/11/78		Edc
Nigeria-C	1409	Recent	190	053	0			17/12/86		Eosat
Nigeria-C		Historic	204	053	100			7/12/75		Edc
Nigeria-S	1403	Recent	191	055	0			18/12/84		Eosat
Nigeria-S		Historic	205	055	90			24/1/79		None
Togo-C	1405	Recent	193	054	0			15/5/87		Eurimage
Togo-C		Historic	207	054	75			28/12/75		Edc
Upper Volta-S	1406	Recent	196	052	0			6/12/90		Eurimage
Upper Volta-S		Historic	210	052	45		A	7/11/75		Edc
Upper Volta-S		Historic	211	052	60		B	14/11/72		Edc
Liberia-E	1402	Recent	198	056	0	TM		14/12/88		Rsc
Liberia-E		Historic	213	056	70			22/1/74		Edc
Guinea-E	1404	Recent	200	054	0			28/12/88		Eurimage
Guinea-E		Historic	215	054	90			28/2/76	6/1/74	Edc
Sierra Leone-S	1401	Recent	201	055	0			19/12/88		Eurimage
Sierra Leone-S		Historic	216	055	100			7/1/74		Edc
SR 13 - East and East Sahelian Africa										
Ethiopia-C	1302	Recent	166	053	0			23/11/89		Eosat
Ethiopia-C		Historic	179	053	75			11/1/80		Eosat
Ethiopia-C	1301	Recent	167	054	0			16/12/86		Eosat
Ethiopia-C		Historic	179	054	75			11/1/80		Eosat
Ethiopia-S	1307	Recent	168	057	0			5/1/86		Eosat
Ethiopia-S		Historic	180	057	70			24/1/76	25/12/72	Edc
Ethiopia-S		Historic	181	057	40			31/12/78		Edc
Ethiopia-C	1306	Recent	171	054	0			28/12/86		Eosat
Ethiopia-C		Historic	183	054	40			10/12/79		Eosat
Ethiopia-C		Historic	184	054	70			29/12/79		Eosat
Ethiopia-S	1305	Recent	171	055	0			10/11/86		Eosat
Ethiopia-S		Historic	183	055	40	BW		28/12/72		Edc
Ethiopia-S		Historic	184	055	65			23/12/75		Edc
Uganda-Equ	1308	Recent	171	059	0			10/1/86		Eosat
Uganda-Equ		Historic	183	059	50			6/3/79	2/2/73	Eosat
Uganda-Equ		Historic	184	059	50			29/1/74		Edc
Uganda-Equ	1309	Recent	172	059	0			17/1/86		Eosat
Uganda-Equ		Historic	184	059	60			29/1/74		Edc
Uganda-Equ		Historic	185	059	60			24/12/75		Edc
Sudan-S	1303	Recent	173	055	0			8/1/86		Eosat
Sudan-S		Historic	186	055	80			2/1/79		Eosat
Zaire/Uganda-Eq	1304	Recent	173	060	0			29/5/88		Eosat
Zaire/Uganda-Eq		Historic	185	060	40			4/2/73		Edc
Zaire/Uganda-Eq		Historic	186	060	70			12/3/75		Edc
Sudan-S	1310	Recent	175	056	0			22/1/86		Eosat
Sudan-S		Historic	188	056	95			9/12/75		Edc

SUBREGION and Location	Sample Code	Acquisition	Path	Row	Overlay of hist. image	Sensor (blanck =MSS)	Sub-Code	DATE d/m/y	DATE2 d/m/y	Supplier
SR 15 - Central Africa										
Zaire-S	1510	Recent	172	068	0			4/7/89		Nasa
Zaire-S		Historic	184	068	60		B	20/7/79		Eosat
Zaire-S		Historic	185	068	50		A	13/6/81		Nasa
Zaire-C	1504	Recent	173	064	0			27/7/89		Nasa
Zaire-C		Historic	185	064	50		A	28/6/73		Edc
Zaire-C		Historic	186	064	60		B	4/7/79		Eosat
Zaire-S	1508	Recent	173	067	0			25/6/89		Nasa
Zaire-S		Historic	185	067	50		A	13/6/81		Nasa
Zaire-S		Historic	186	067	60		B	22/7/79		Eosat
Zaire-S	1506	Recent	174	065	0			16/6/89		Nasa
Zaire-S		Historic	186	065	50			4/7/79		Eosat
Zaire-S		Historic	187	065	70			5/7/79		Eosat
C.A.Rep-C	1509	Recent	176	056	0			29/1/86		Eosat
C.A.Rep-C		Historic	189	056	100			16/12/72		Edc
Zaire-S	1507	Recent	176	066	0			30/6/89		Nasa
Zaire-S		Historic	189	066	80			17/6/81		Nasa
Zaire-Eq	1502	Recent	177	059	0			4/1/86		Eosat
Zaire-Eq		Historic	190	059	100			17/3/73		Edc
Zaire-C	1505	Recent	177	064	0			5/6/89		Nasa
Zaire-C		Historic	190	064	95			6/7/81		Nasa
C.A.Rep-N	1511	Recent	180	055	0	TM		23/1/88		Eosat
C.A.Rep-N		Historic	193	055	75			14/12/75		Edc
C.A.Rep-S	1512	Recent	183	056	0			1/1/87		Eosat
C.A.Rep-S		Historic	196	056	50		A	28/1/73		Edc
C.A.Rep-S		Historic	197	056	50		B	23/1/76		Edc
Cameroon-Eq	1501	Recent	186	058	0	TM		2/2/88		Eosat
Cameroon-Eq		Historic	200	058	75			1/2/73		Edc
Eq.Guinea-Eq	1503	Recent	186	059	0	TM		7/2/90		Eosat
Eq.Guinea-Eq		Historic	200	059	75			1/2/73		Edc
SR 16 - Southern Africa										
Mozambique-N	1601	Recent	164	071	0			13/8/89		Nasa
Mozambique-N		Historic	176	071	75			8/8/79		Eosat
Mozambique-N	1610	Recent	165	069	0			16/7/88		Nasa
Mozambique-N		Historic	177	069	90			23/6/81		Nasa
Tanzania-S	1604	Recent	166	067	0			8/6/89		Nasa
Tanzania-S		Historic	178	067	100			16/7/82		Nasa
Mozambique-S	1606	Recent	167	076	0			17/5/87		Nasa
Mozambique-S		Historic	179	076	90			31/5/79		Eosat
Mozambique-N	1608	Recent	168	071	0			17/6/87		Nasa
Mozambique-N		Historic	180	071	100			26/6/81	15/6/78	Nasa
Zambia-C	1603	Recent	171	070	0			27/6/89		Nasa
Zambia-C		Historic	183	070	75			29/6/81		Nasa
Zambia-C		Historic	184	070	40					Nasa
Zambia-C	1607	Recent	174	070	0			15/5/89		Nasa
Zambia-C		Historic	186	070	50					Nasa
Zambia-C		Historic	187	070	70			10/5/81		Nasa
Angola-S	1605	Recent	179	071	0			3/6/89		Nasa
Angola-S		Historic	192	071	95			20/6/81	15/2/73	Nasa
Namibia-N	1609	Recent	179	073	0			18/5/89		Nasa
Namibia-N		Historic	192	073	95			15/5/81		Nasa
Angola-N	1602	Recent	182	067	0			11/8/89		Nasa
Angola-N		Historic	195	067	75			18/5/81		Nasa
Angola-N		Historic	196	067	30					Nasa
Angola-N	1611	Recent	178	066	0			27/5/89		Nasa
Angola-N		Historic	191	066	100			19/6/81		Nasa

SUBREGION and Location	Sample Code	Acquisi-tion	Path	Row	Over-lay of hist. image	Sensor (blanck= MSS)	Sub-Code	DATE d/m/y	DATE2 d/m/y	Supplier
Angola-N	1614	Recent	179	067	0			15/5/88		Nasa
Angola-N		Historic	192	067	100			15/5/81		Nasa
Zambia	1612	Recent	172	069	0			2/6/89		Nasa
Zambia		Historic	184	069	45			30/6/81		Nasa
Zambia		Historic	185	069	65			13/6/81		Nasa
Mozambique-N	1615	Recent	166	070	0			3/6/87		Nasa
Mozambique-N		Historic	178	070	100			23/7/79		Eosat
Zimbabwe	1613	Recent	169	074	0			12/5/89		Nasa
Zimbabwe		Historic	181	074	100			22/5/81		Nasa
SR 31 - Central America										
Belize-Mexico	3101	Recent	019	048	0	SPOT		15/2/90	14/12/87	Eosat
Belize-Mexico		Historic	020	048	100			14/11/80		Eosat
Nicaragua/Hondu	3102	Recent	016	050	0			28/1/86		Eosat
Nicaragua/Hondu		Historic	017	050	70			24/1/79		Eosat
Nicaragua/Hondu	3103	Recent	015	050	0	TM		8/4/88		Eosat
Nicaragua/Hondu		Historic	016	050	70			1/4/78		Edc
Honduras	3106	Recent	017	049	0			20/2/86		Eosat
Honduras		Historic	018	049	80			7/1/79		Eosat
Mexico-S	3107	Recent	024	049	0			23/11/90		Eosat
Mexico-S		Historic	025	049	70			7/11/79		Eosat
Mexico-S	3104	Recent	022	049	0			25/11/90		Eosat
Mexico-S		Historic	023	049	85			5/12/75		Edc
Mexico-N	3105	Recent	034	039	0			19/6/89		Eosat
Mexico-N		Historic	034	039	100			3/6/83		Eosat
Mexico/Belize	3109	Recent	019	047	0			20/11/90		Eosat
Mexico/Belize		Historic	020	047	100			1/2/78		Edc
Mexico-C	3108	Recent	027	044	0			12/11/90		Eosat
Mexico-C		Historic	028	044	45			13/11/80		Eosat
Mexico-C		Historic	028	044	65			14/11/80		Edc
Guatemala/Elsal	3110	Recent	019	050	0			14/12/87		Eosat
Guatemala/Elsal		Historic	020	050	100			5/2/79		Eosat
SR 35 - Brazil										
Amazonas	3501	Recent	229	064	0			25/7/91		Inpe
Amazonas		Historic	246	064	100	BW		27/6/78		Inpe
Rondonia	3502	Recent	230	069	0			3/6/87	14/8/90	Inpe
Rondonia		Historic	247	069	95			1/8/80	17/6/75	Edc
Mato Grosso	3503	Recent	226	069	0			21/10/90	2/8/90	Inpe
Mato Grosso		Historic	243	069	65	BW		28/6/79	12/9/73	Edc
Mato Grosso		Historic	242	069	40			22/10/72		Edc
Amazonas	3504	Recent	230	060	0			12/9/89		Inpe
Amazonas		Historic	247	060	100	BW		6/10/76		Inpe
Mato Grosso	3505	Recent	227	069	0			26/9/90		Inpe
Mato Grosso		Historic	243	069	40		B	12/9/73		Ibama
Mato Grosso		Historic	244	069	70		A	14/6/75		Edc
Mato Grosso	3506	Recent	228	067	0			1/9/90		Inpe
Mato Grosso		Historic	245	067	85	BW		30/6/79		Inpe
Mato Grosso	3507	Recent	225	069	0			7/7/89		Inpe
Mato Grosso		Historic	241	069	55			5/8/73		Edc
Mato Grosso		Historic	242	069	55			22/10/72		Edc
Piaui	3508	Recent	219	065	0	TM		17/8/90		Inpe
Piaui		Historic	235	065	100			9/9/72		Edc
N-Coast	3509	Recent	222	061	0			31/7/88		Inpe
N-Coast		Historic	239	061	60	BW		6/8/81		Inpe

SUBREGION and Location	Sample Code	Acquisition	Path	Row	Overlay of hist. image	Sensor (blanck =MSS)	Sub-Code	DATE d/m/y	DATE2 d/m/y	Supplier
Marhanhao	3510	Recent	221	063	0			11/11/87	17/6/86	Inpe
Marhanhao		Historic	237	063	80	BW		31/7/75		Edc
Bahia	3511	Recent	217	069	0	TM		25/5/88		Inpe
Bahia		Historic	233	069	95			15/8/73		Edc
Piaui	3512	Recent	221	066	0			15/8/90		Inpe
Piaui		Historic	237	066	90			1/8/73		Edc
Mato Grosso	3513	Recent	225	070	0			11/8/90		Inpe
Mato Grosso		Historic	241	070	60			5/8/73		Edc
Mato Grosso		Historic	242	070	50			22/10/72		Edc
Minas Gerais	3514	Recent	218	073	0	TM		9/7/90		Inpe
Minas Gerais		Historic	234	073	95	BW		29/7/73		Edc
Mato Grosso D.S	3515	Recent	225	073	0			21/6/89		Inpe
Mato Grosso D.S		Historic	241	073	60			15/9/72		Edc
Mato Grosso D.S		Historic	242	073	40			15/3/73		Edc
Mato Grosso D.S	3516	Recent	226	074	0			5/8/90	19/11/89	Inpe
Mato Grosso D.S		Historic	242	074	60			29/5/81		Eosat
Mato Grosso D.S		Historic	243	074	50			19/7/75		Edc
Santa Catarina	3517	Recent	220	078	0	TM		14/5/88		Inpe
Santa Catarina		Historic	236	078	95			16/7/81		Eosat
SR 34 - South America (excuded Brazil)										
Suriname/Fr Guy	3401	Recent	228	057	0	TM		10/4/89		Inpe
Suriname/Fr Guy		Historic	245	057	100			31/10/76		Inpe
Bolivia-N	3402	Recent	002	069	0	TM		1/8/90		Inpe
Bolivia-N		Historic	001	069	85			4/8/77		Inpe
Peru-C	3403	Recent	006	065	0	TM		13/6/91		Inpe
Peru-C		Historic	006	065	80			4/10/75		Inpe
Peru-C	3404	Recent	007	065	0	TM		19/7/90	25/8/89	Eosat
Peru-C		Historic	007	065	80			24/8/76		Inpe
Colombia-S	3405	Recent	006	060	0	TM		11/9/89		Inpe
Colombia-S		Historic	006	060	85			23/1/77		Inpe
Bolivia-W	3406	Recent	002	070	0	TM		3/6/86		Inpe
Bolivia-W		Historic	001	070	90			4/8/77		Inpe
Peru-C	3407	Recent	007	067	0	TM		24/7/89		Eosat
Peru-C		Historic	007	067	80			23/7/77		Inpe
Venezuela-E	3408	Recent	233	056	0	TM		4/3/87		Eosat
Venezuela-E		Historic	250	056	70			11/2/79		Eosat
Venezuela-E		Historic	251	056	40			7/1/79		Eosat
Bolivia/Brazil	3409	Recent	229	071	0	TM		25/7/91		Inpe
Bolivia/Brazil		Historic	246	071	85			2/8/78		Inpe
Bolivia-S	3410	Recent	231	073	0	TM		25/7/91		Inpe
Bolivia-S		Historic	248	073	100			4/8/78		Inpe
Venezuela-E	3411	Recent	001	055	0			25/4/86		Eosat
Venezuela-E		Historic	251	055	55		A	29/8/79		Inpe
Venezuela-E		Historic	001	055	55		B	31/12/76		Inpe
Colombia-S	3412	Recent	009	058	0	TM		7/8/89		Eosat
Colombia-S		Historic	009	058	100			1/2/76		Edc
Bolivia-C	3413	Recent	232	070	0	TM		8/7/89		Inpe
Bolivia-C		Historic	249	070	100			26/9/80		Inpe

SUBREGION and Location	Sample Code	Acquisition	Path	Row	Overlay of hist. image	Sensor (blanck =MSS)	Sub-Code	DATE d/m/y	DATE2 d/m/y	Supplier
SR 44 - South Asia										
N-E Coast	4401	Recent	138	045	0	TM		27/11/89		Fsi
N-E Coast		Historic	148	045	80			5/12/75		Edc
N Himalays Bndy	4402	Recent	146	039	0	TM		8/5/88	15/10/89	Fsi
N Himalays Bndy		Historic	157	039	100			26/2/79		Eosat
South Extreme	4403	Recent	143	054	0	TM		26/2/87	23/4/90	Fsi
South Extreme		Historic	154	054	65			9/2/73		Edc
South Extreme		Historic	153	054	40			26/2/73		Edc
N-E Coast	4404	Recent	148	044	0	TM		19/10/90		Fsi
N-E Coast		Historic	159	044	100			4/11/76		Edc
N-E Bdr/S Bhutan	4405	Recent	137	042	0	TM		23/11/90	7/1/90	Fsi
N-E Bdr/S Bhutan		Historic	147	042	85			8/2/77		Edc
Sth Himalaya	4406	Recent	149	037	0	TM		20/10/88		Fsi
Sth Himalaya		Historic	160	037	90			11/11/75		Edc
Nepal Border	4407	Recent	143	041	0	TM		17/11/90		Fsi
Nepal Border		Historic	154	041	70			17/12/79		Eosat
Nagaland	4409	Recent	135	042	0	TM		5/2/88		Fsi
Nagaland		Historic	145	042	90			6/12/81		Fsi
North Central	4408	Recent	145	043	0	TM		24/10/88		Fsi
North Central		Historic	156	043	90			1/11/76		Edc
Orissa	4410	Recent	142	046	0	TM		10/11/90		Fsi
Orissa		Historic	152	046	75			7/10/80		Fsi
Orissa		Historic	153	046	25			8/10/80		Fsi
SR 45 - South East Continental Asia										
Vietnam-C	4501	Recent	126	048	0			6/2/88		Local
Vietnam-C		Historic	135	048	80			26/2/73		Edc
Vietnam/Cambod.	4502	Recent	124	051	0			10/2/89		Local
Vietnam/Cambod.		Historic	133	051	100			24/2/73		Edc
Vietnam	4503	Recent	124	052	0			28/1/90		Local
Vietnam		Historic	133	052	100			31/1/76		Edc
Cambodia	4504	Recent	127	051	0			5/2/91		Local
Cambodia		Historic	136	051	80			16/1/76		Edc
Thailand/Laos	4505	Recent	129	048	0	TM		18/11/91		Local
Thailand/Laos		Historic	138	048	50			18/1/76		Eosat
Thailand/Laos		Historic	139	048	60			19/1/76		Local
Thailand	4506	Recent	128	049	0	TM		17/4/91		Local
Thailand		Historic	137	049	65			17/1/76		Eosat
Thailand		Historic	138	049	40			18/1/76		Local
Laos South	4507	Recent	128	047	0			29/3/90		Local
Laos/South		Historic	137	047	55		B	7/10/79		Local
Laos South		Historic	138	047	55		A	18/1/76		Edc
Thailand	4508	Recent	129	054	0	TM		4/3/90		Local
Thailand		Historic	138	054	65			1/3/73		Eosat
Thailand		Historic	139	054	40			2/3/73		Local
Vietnam/China	4509	Recent	126	045	0			23/11/89		Local
Vietnam/China		Historic	135	045	70		A	29/12/73		Edc
Vietnam/China		Historic	136	045	40		B	29/12/75		Edc
Thailand/Myanmar	4510	Recent	130	050	0	TM		12/4/90		Local
Thailand/Myanmar		Historic	139	050	45			7/1/73	31/1/77	Eosat
Thailand/Myamnar		Historic	140	050	60			26/1/73	18/2/79	Eosat

SUBREGION and Location	Sample Code	Acquisition	Path	Row	Over-lay of hist. image	Sensor (blanck =MSS)	Sub-Code	DATE d/m/y	DATE2 d/m/y	Supplier
SR 46 - South East Insular Asia										
Irian Jaya-N	4601	Recent	105	061	0	TM		2/4/89		Eosat
Irian Jaya-N		Historic	112	061	70			18/11/73		Edc
Irian Jaya-N		Historic	113	061	40					
Sumatra-C	4602	Recent	127	061	0			20/4/89		Lapan
Sumatra-C		Historic	136	061	95					None
Pap. N.Guinea-C	4603	Recent	099	064	0					None
Pap. N.Guinea-C		Historic	106	064	100			19/8/72		Edc
Kalimantan-E	4604	Recent	117	061	0			23/2/88	8/3/87	Lapan
Kalimantan-E		Historic	125	061	75					None
Celebes-N	4605	Recent	114	061	0			27/9/87		Lapan
Celebes-N		Historic	122	061	100			28/10/72		Edc
Sumatra-S	4606	Recent	125	063	0			27/7/89		Lapan
Sumatra-S		Historic	134	063	95			13/6/73		Edc
Sumatra-N	4607	Recent	127	059	0			20/4/89		Lapan
Sumatra-N		Historic	136	059	95					None
Philippines-S	4608	Recent	113	055	0	TM		25/12/90		Eosat
Philippines-S		Historic	121	055	100			6/2/76		Edc
Philippines-N	4609	Recent	116	048	0	TM		9/1/89		Eosat
Philippines-N		Historic	125	048	65			21/2/79		Eosat
Sumatra-S	4610	Recent	124	063	0			1/5/89		Lapan
Sumatra-S		Historic	133	063	85			22/6/78		Edc

ANNEX 10
(Section 3.2.1)

Regional Workshops
Summary of Conclusions and Recommendations

TCDC WORKSHOP ON METHODOLOGY FOR DEFORESTATION ASSESSMENT IN SOUTH EAST ASIA

BANGKOK 6 - 17 MAY 1991

SUMMARY

Funding Agencies
Unit of Technical Cooperation among Developing Countries (TCDC), United Nations Development Program

Implementing Agencies
Royal Forest Department of Thailand and FAO Regional Office for Asia and the Pacific (RAPA), within the framework of the Forest Resources Assessment 1990 Project , with the former also as host institution.

Participants
Seventeen national resource specialists from nine countries:
India, Indonesia, Laos, Malaysia, Myanmar, Papua New Guinea, Philippines, Thailand, Vietnam.

Location
Royal Forest Department, Remote Sensing and Forest Mapping Division, Bangkok, Thailand.

CONCLUSIONS AND RECOMMENDATIONS

Classification

1. The Workshop underscored that FAO's classification of woody vegetation cover for the interpretation of high resolution satellite data is based on physiognomic aspects in order to assess the changes of forest area as well as the changes of forest density.
2. The Workshop agreed that there is a need for having a common classification structure that would make the results produced in various countries compatible and would allow consistent synthesis at national. sub-regional, regional and global levels.
3. The Workshop noted that it is necessary and appropriate for a country to reserve the freedom and flexibility to further sub-divide the proposed classes into more specific classes in order to meet the requirements at national level. Such further sub-division could include specific forest formations and floristic groups such as: coniferous and broadleaved forest; mangrove forest; bamboo forest; etc.
4. The Workshop expressed a necessity to further consider the aspects of the possibility to differentiate with accuracy canopy density and height thresholds.
5. The Workshop noted that there is possible confusion between the proposed physiognomic classes for image interpretation and the traditional classes (mainly based on ecological parameters) used by FAO when reviewing existing national forest statistics. The Workshop, therefore, suggested that separate terminology be applied in order to avoid such possible confusion.
6. The Workshop supported the need expressed by FAO that each study carried out using the FAO methodology and classification be correlated by detailed documentation and comments of the interpreter regarding the classes identified and detailed comments on the estimated level of reliability of class delineation.
7. The Workshop concluded that the proposed classification should be adopted, with the considerations expressed above, in this first run of deforestation and forest degradation studies in the framework of FAO

Forest Resources Assessment 1990 Project. The experience and results deriving from such studies will allow to further review and improve the classification.

Interpretation Procedure

8. The Workshop recommended that the interpretation of multi-date satellite data be carried out in an inter-dependent way as proposed by FAO Guideline under Procedure is the most appropriate for a consistent assessment of changes in forest area and quality.
9. The Workshop emphasized the importance of background data such as topographic maps, land use maps, forest type maps, ecological maps, aerial photographs, etc. and field verification for a reliable interpretation of satellite data.

Data Processing

10. The Workshop recommended that the results of the multi-date satellite interpretation be processed in the form of change matrix in order to allow a thorough analysis of the class to class changes in the areas studied.
11. The Workshop considered the data processing procedure proposed by FAO, based on the use of dotgrid and subsequent entry of class codes in computerized spreadsheet files, simple and appropriate to process the interpretation results and produce class-to-class change matrices.

Other Issues

12. The Workshop recommended that such TCDC cooperative action on the issue of forest resources monitoring in the Region be continued with special reference to the countries that could not participate at the present TCDC Workshop, e.g. Pakistan, Sri Lanka, Nepal, Kampuchea, Bhutan, Brunei, Bangladesh, Fiji and other pacific islands countries.
13. The Workshop recommended to establish a regional network between government agencies and other institutions to exchanges and disseminate the forest resources information on a continuing basis.

WORKSHOP ON METHODOLOGY FOR DEFORESTATION AND FOREST DEGRADATION ASSESSMENT IN AFRICA

NAIROBI 25 NOVEMBER - 13 DECEMBER 1991
(first regional workshop)

SUMMARY

Funding Agencies
United States Forest Service (USFS) of The United States Department of Agriculture, Food and Agriculture Organization of the United Nations.

Implementing Agencies
FAO Forest Resources Assessment 1990 Project was responsible for technical implementation and administration; the United Nations Environmental Program (UNEP-GRID) was the host institution.

Participants
Eighteen national resource specialists from 9 countries:
Kenya, Mozambique, Nigeria, Sudan, Tanzania, Uganda, Zaire, Zambia, Zimbabwe

Location
UNEP/GRID Headquarters, Nairobi, Kenya.

CONCLUSIONS AND RECOMMENDATIONS

The workshop concluded that the methodology presented by the Project is appropriate and recommended its application for continuous forest monitoring studies.
The following aspects were discussed in detail:

A. Satellite image quality
B. Classification
C. Interdependent interpretation procedure
D. Data processing procedure

A. Satellite image quality.

Background: The images for this workshop were obtained from a variety of sources. The processing was therefore done by several different methods, none of which were documented.

1. Considering the above, the workshop recommended that the data should be produced following a standardized production process, which should be duly documented.
2. The workshop recognized the need for the development of suitable enhancements and band combinations to allow the detection and delineation of woody vs non-woody vegetation types for all ecological conditions.
3. The workshop considered that for the drier areas the standard processing level of satellite images may not meet the minimum acceptable requirements for visual delineation of woody vegetation and recommended that for such areas a more specific approach should be studied and identified.
4. With regard to the drier areas, the workshop recommended that the timing of image acquisition be carefully considered, so that the date of acquisition coincide with the season when the undergrowth vegetation has dried, but the trees have not yet lost their leaves.
5. With reference to the multi-date interdependent interpretation approach the workshop recommended that both images covering the same area be treated in a comparable way to render more consistent the analysis of changes.
6. The workshop recommended that the two images covering a given area be printed at exactly the same scale in order to minimize the difficulties arising from different map projections.
7. The workshop recommended that future assessments of forest change make use of other types of high resolution satellite data, as they become available.

B. Classification

1. The workshop recognized the need for, and recommended the use of, a standard classification of woody vegetation based on physiognomic characteristics in order to allow consistent synthesis of survey results at national, sub-regional, regional and global levels. The workshop noted that it is necessary and appropriate for a country to reserve the freedom and flexibility to further subdivide the standard classes into more specific classes in order to meet the requirements at a national level. Such further subdivision, which must be structured in a consistent hierarchical fashion, could include specific forest formations and floristic groups.
2. The workshop noted that the level of reliability in class delineation strongly depends on ground knowledge and the use of other reference data, such as aerial photographs.
3. The workshop also noted that difficulties in class delineation depended on three main factors:
    - image quality
    - direct knowledge of the area studied
    - level of familiarity with the classification structure and thresholds

   The workshop emphasized that there is need for improvement in all three aspects listed above.
4. The workshop recognized the need to relate the classification to the images, as specifically as possible, and recommended the development of a visual interpretation key for at least the main classes. From the workshop's experience with the variations in image quality, it is recommended that the key be based on texture and patterns, rather than image tone.

C. Interdependent interpretation procedure

1. The workshop recommended the use of an interdependent interpretation approach in order to achieve a consistent assessment of changes in woody vegetation.
2. The workshop noted that the interdependent interpretation approach optimizes the information available in the images, since the interpretation of each image benefits from the information available on the other image.
3. The workshop stressed the importance of having corresponding images produced at the same scale in order to allow a complete and smooth application of the interdependent analysis procedure.

D. Data processing procedure

1. The workshop recommended that the results of the multi-date satellite data interpretation be processed in the form of a change matrix in order to allow a site-specific analysis of the class-to-class changes in the areas studied.
2. The workshop agreed that the processing procedure presented by FAO is simple and appropriate for processing the interpretation results, since it is based on equipment and software which is widely available.
3. The workshop agreed that the processing programmes could be improved or modified as needed in future.

E. Other issues

1. The workshop recommended that a standardized procedure be developed for accuracy assessment of the interpretation.
2. The workshop recommended, in view of point B.2, that a standard ground truthing procedure be developed and that FAO allocate appropriate funding for the task.
3. The workshop recommended that FAO continue to support the member countries in the monitoring of forest resources by:
    1. Continuing training activities and programs.
    2. Networking of regional and national institutions.
    3. Financial and material support such as purchase of satellite images and support of ground truthing activities.
    4. Promoting the implementation of continuous forest cover monitoring at global, regional and sub-regional levels.

WORKSHOP ON METHODOLOGY FOR DEFORESTATION AND FOREST DEGRADATION ASSESSMENT IN LATIN AMERICA

MEXICO CITY 15 MARCH - 2 APRIL 1993

SUMMARY

Funding Agencies
United States Forest Service (USFS) of The United States Department of Agriculture, Food and Agriculture Organization of the United Nations.

Implementing Agencies
FAO Forest Resources Assessment 1990 Project was responsible for technical implementation and administration; the Institute of Geography of the National Autonomous University Of Mexico was the host institution.

Participants
Twenty one national resource specialists from ten countries:
Bolivia, Brazil, Colombia, Equador, Honduras, Mexico, Nicaragua, Paraguay, Peru, Venezuela.

Location
Institute of Geography of the National Autonomous University Of Mexico, Mexico City.

CONCLUSIONS AND RECOMMENDATIONS OF THE WORKSHOP

(English Translation)

1 Regarding the quality of the imagery
The workshop recommends the inclusion of better quality images with less distortion for future assessments, preferably co-registered (historical to recent, or to a common geographical reference)

2 Regarding the classification

- The workshop considers the classification to meet the objectives of forest resources assessment.
- The workshop recommends that the classification be documented by means of detailed studies supported by field verification, aerial photos or imagery of greater resolution.
- The workshop recommends to document the relationship between the general classification (used for the global survey) and the classification systems traditionally used by each country, with the objective of improving of the comprehension and consistency of the general classification.

3 Regarding the interdependent interpretation method

- The workshop recommends the application of this method of interpretation since the interdependent analysis of the two images allows to compensate for poor quality of one of the two images, it minimise the error (due to independent, subjective delineations) and allows a better delineation of the classes.

4 Regarding the processing of the data

- It is concluded that it is a simple technique, which does not require sophisticated equipment and which facilitates distribution of the process at the province and local levels.

5 Practical recommendations for the workshop

- That the spatial analysis be included in the methodology by means of a simple and easily available [GIS] package.
- That the FAO provide tools and common methodologies which will facilitate the analysis and communication between countries.
- The workshop recommends that the FAO orient the activities of the program to central and concrete themes which can be sessions regarding the impacts of deforestation and forest degradation at the regional (continental) level.

General recommendations

The workshop participants recommend that the FAO continue with the forest resources assessment and the distribution of the methodology for multi-temporal monitoring in all countries; and confirm the desire to actively participate in these studies.

The personal contact established between the participants is considered to be an important result of the workshop; for the exchange of experiences, the application of specific techniques, and everything related to resource assessment.

It is recommended that FAO actively support this network (of communications) by means of seminars/workshops for evaluation and analysis of the regional results of the FAO forest assessment project, and for the interchange of experiences with the application of the methodology at the national level.

WORKSHOP ON METHODOLOGY FOR DEFORESTATION AND FOREST DEGRADATION ASSESSMENT IN AFRICA

YAOUNDE 28 FEBRUARY - 18 MARCH 1994
(second regional workshop)

SUMMARY

Funding Agencies
The European Community (EEC) and the Food and Agriculture Organization of the United Nations (FAO).

Implementing Agencies
FAO Forest Resources Assessment 1990 Project was responsible for technical implementation and administration; the National Office of Forest Development (ONADEF) was the host institution.

Participants
Twenty seven National resource specialists from twelve Central and West African countries:
Angola, Cameroon, Central African Republic, Congo, Equatorial Guinea, Gabon, Guinée, Ivory Coast, Liberia, Nigeria, Sierra Leone, and Zaire.

Location
Ecole Nationale Superieure Polytechnique, Yaoundé, Cameroon.

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

- Concerning the quality of the satellite images, the participants acknowledge FAO's efforts in providing good quality images of the region.
- The procedure of interdependent interpretation, which allows to work on multidate images from one location was judged to be the most reliable methodology on account of it's coherence and logic.
- The data compilation procedure was found satisfactory and the application of Lotus Software, compatible with other common software was found appropriate. It also enables the presentation of results in the form of change matrices which are easy to produce and interpret.
- The FAO vegetation classification caused some difficulties concerning its terminology compared to the various National classifications.
- Considering that the FAO methodology allows vegetation state and change assessment, the participants recognize the need and opportunity to install in each country remote sensing facilities.

RECOMMENDATIONS

Following the above conclusions, the participants have adopted the following recommendations:

- FAO should make efforts to provide satellite images to the Project countries.
- FAO should continue to disseminate the methodology for deforestation and forest degradation assessment.
- Regarding the introduction and standardization of the FAO classification for the pantropical zone, the workshop recommends to every country of the region to correlate their National classifications with the FAO classification.
- As a follow up to the workshop, the participants recommend that each country should make an effort to install computer equipment. In particular, they recommend FAO to encourage these National initiatives and provide assistance.
- For a better transfer of the methodology the workshop recommends the creation of permanent regional training centres.

ANNEX 11
(Section 4.1)

Example of results and analysis at individual sampling unit level: SU 4409 - North East India

	Path / row	Sensor	Date
Recent image	**135 / 42**	**TM**	**05 February 1988**
Historical image	**145 / 42**	**MSS**	**06 December 1981**

State assessment results based on the interpretation of the entire recent image

Main Classes	'000 ha	%	Additional classes	'000 ha	%
Closed Forest	**1230.4**	*40.3*	c.c. >70 % c.c. 40 - 70 %		
Open Forest	**45.2**	*1.5*			
Long Fallow	**783.2**	*25.7*			
Fragm.Forest	**189.2**	*6.2*	Forest fraction 40-70 %	**189.2**	*6.2*
			Forest fraction 10-40 %	**0.0**	*0.0*
Shrubs	**50.4**	*1.7*	Dense (c.c.>40 %) Sparse (c.c. 10-40 %)		
Short Fallow	**0.0**	*0.0*			
Other Land Cov.	**687.2**	*22.5*	Snowcaps, rocky areas		
Water	**12.0**	*0.4*			
Man-made woody vegetation	**53.2**	*1.7*	Forest plantations	**0.0**	*0.0*
			Agricultural plantations	**53.2**	*1.7*
Total visible area	**3050.8**	*100.0*			
Other non interpreted	**12.4**		Burnt woodland	**0.0**	
			Clouds and shadows	**12.4**	
			Mountain shadows	**0.0**	

Change matrix of Sampling Unit 4409 in North East India [1]
Period covered: December 1981 - February 1988

	Interpretation classes of recent image (thousand hectares)									TOTAL historical image	
Interpretation classes of historical image	**Closed Forest**	**Open Forest**	**Long Fallow**	**Frag-mented Forest**	**Shrubs**	**Short Fallow**	**Other Land Cover**	**Water**	**Planta-tion**	**'000 ha**	**%**
Closed Forest	1078.0	0.8	46.0	21.6	1.2		25.2		2.4	**1175.2**	***42.0***
Open Forest	0.8	40.8		0.4	1.6		1.6			**45.2**	***1.6***
Long Fallow	6.0		683.6	80.8	12.0		47.2		0.4	**830.0**	***29.7***
Fragmented Forest	6.8		18.4	**80.8**	0.4		7.6			**114.0**	***4.1***
Shrubs					30.4					**30.4**	***1.1***
Short Fallow											
Other Land Cover	1.2		8.8	0.8			532.8			**543.6**	***19.4***
Water								10.4		**10.4**	***0.4***
Plantation							0.8		46.8	**47.6**	***1.7***
TOTAL recent image '000 ha	**1092.8**	**41.6**	**756.8**	**184.4**	**45.6**	**0.0**	**615.2**	**10.4**	**49.6**	**2796.4**	
TOTAL recent image %	***39.1***	***1.5***	***27.1***	***6.6***	***1.6***	***0.0***	***22.0***	***0.4***	***1.8***		***100.0***

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[1] Results based on visible common area between recent and historical satellite images.

RESULTS BY LAND COVER CATEGORIES[2]

1) Changes in CONTINUOUS NATURAL FOREST LAND

Classes: Closed Forest Open Forest Long Fallow

	Conv. to Manm. W. Veg	Amelio-ration	Unchanged	Degradat.	Fragment. (partial defor.)	Deforestation To Other Wooded	Deforestation To Non Wooded	Total Cont. Forest land (Dec.1981)
Change '000ha	2.8	6.8	1802.4	46.8	102.8	14.8	74.0	2050.4
Annual '000ha	0.5	1.1		7.8	17.1	2.5	12.3	
Annual rate %	0.02	0.06		0.36	0.84	0.12	0.60	

2) Changes in FRAGMENTED NATURAL FOREST LAND

Class Fragmented Forest; composed by a mosaic of Forest / Non-Forest. **Estimated Forest Fraction : 0.33**

	Conv. to Manm. W. Veg	Natural Affor.	Unchanged	(Partial deforest.) To Other Wooded	(Partial deforest.) To Non Wooded	Tot.Fragm. For. Land (Dec.1981)
Change '000ha		25.2	80.8	0.4	7.6	114.0
Annual '000ha		4.2		0.1	1.3	
Annual rate %		3.68		0.06	1.11	

Estimated area and changes of ACTUAL FOREST AREA
within "Fragmented Forest" Class:

	net area	net aff.	Unch.forest	(Net deforestation)		Net Forest
Change '000ha		16.9	26.7	0.1	2.5	37.6
Annual '000ha		2.8		0.0	0.4	
Annual rate %		7.48		0.06	1.11	

3) Changes in OTHER WOODED LAND

Classes: Shrubs, Short Fallow

	Conv. to Manm. W. Veg	Natural afforestation Cont.	Natural afforestation Fragm.	Amelio-ration	Unchanged	Degradation moderate	Degradation complete	Total Other Wood.Land (Dec.1981)
Change '000ha					30.4			30.4
Annual '000ha								
Annual rate %								

4) Changes in NON WOODED AREAS

Classes: Other Land Cover, Water

	Conv. to Manm. W. Veg	Natural afforestation Cont.	Natural afforestation Fragm.	Amelio-ration	Unchanged	Total Non Wood.Area (Dec.1981)
Change '000ha		10.0	0.8		543.2	554.0
Annual '000ha		1.7	0.1			
Annual rate %		0.30	0.02			

5) Changes of MANMADE WOODY VEGETATION

Class Manmade Woody Vegetation (inclusive of both forest and agricultural plantations)

	Tot.New MWVeg (Recent Image)	New Manmade Woody Veg. Created On Previous: Forest Land	New Manmade Woody Veg. Created On Previous: Other W. Land	New Manmade Woody Veg. Created On Previous: Non W. Areas	Unchanged	Changed To: Cont.or Fragm. Forest	Changed To: Other Wooded	Changed To: Non Wooded	Tot Manm. WoodyVeg (Dec.1981)
Change '000ha	2.8	2.8			46.8			0.8	47.6
Annual '000ha	0.5	0.5						0.1	
Annual rate %	0.98	0.98						0.28	

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[2] The terms used are discussed in Section 2.2.1:"Definition of forest and forest area changes".

SUMMARY OF AREA RESULTS

6) Gross Deforestation (loss of natural forest)

Total Gross Deforestation	'000 ha	163.1
Annual Gross Deforestation	'000 ha	27.7
Annual Gross Deforestation	%	1.30

7) Net Deforestation (loss - gain of natural forest)

Total Net Deforestation	'000 ha	136.0
Annual Net Deforestation	'000 ha	22.7
Annual Net Deforestation	%	1.09

8) Net Degradation Of Natural Forest

Total Net Forest Degradation	'000 ha	40.0
Annual Net For.Degradat.Rate	'000 ha	6.7
Annual Net For.Degradat.Rate	%	0.32

9) Net Degradation Of Natural Woody Vegetation

Total Net Degradation	'000 ha	40.0
Annual Net Degradation Rate	'000 ha	6.7
Annual Net Degradation Rate	%	0.32

10) BALANCE NATURAL FOREST - MANMADE WOODY VEGETATION

		Natural Forest Continuous & Fragmented	Manmade Woody Vegetation	Total Natural + Manmade
Area at Dec. 1981	'000 ha	2088.0	47.6	2135.6
Area at Feb. 1988	'000 ha	1952.1	49.6	2001.7
Difference	'000 ha	-136.0	2.0	-134.0
Change Rate	%	-22.7	0.3	-22.3
Annual simple rate	%	-1.09	0.70	-1.05

INDICATIVE ESTIMATES OF BIOMASS CHANGES

	Estim.ed Biomass '000 T/ha	Classes 1990 Biomass 1990	Classes 1980 Biomass 1990	Classes 1980 Biomass 1980	Biomass in Million Tons Loss[3] Defor.	Degrad.	Fragm.	Gain[3] Affor.	Amelior	Manm.	Total Loss[4]	Total Gain[4]	Net Balance
Closed Forest	0.130	142.1	144.5	152.8	-3.6	-3.0	-1.9	-	-	0.3	-8.5	0.3	-8.2
Open forest	0.075	3.1	3.2	3.4	-0.2	0.0	0.0	-	0.0	0.0	-0.2	0.0	-0.2
Long fallow	0.065	49.2	49.3	54.0	-3.3	-	-1.8	-	0.4	0.0	-5.1	0.4	-4.7
Fragm.Forest	0.043	7.9	5.6	4.9	-0.3	-	-	1.0	-	0.0	-0.3	1.0	0.7
Shrubs	0.025	1.1	0.8	0.8	-	0.0	-	0.0	-	0.0	0.0	0.0	0.0
Short Fallow	0.015	0.0	0.0	0.0	-	0.0	-	0.0	0.0	0.0	0.0	0.0	0.0
Oth.Land Cov.	0.005	3.1	3.4	2.7	-	0.0	-	0.7	0.0	0.0	0.0	0.7	0.7
Water		0.0	0.0	0.0	-	-	-	0.0	0.0	0.0	0.0	0.0	0.0
Manm.W.Veg	0.105	5.2	4.9	5.0	-0.1	0.0	0.0	0.0	0.0	0.0	-0.1	0.0	-0.1
Total Biomass		211.7	211.7	223.5	-7.5	-3.0	-3.7	1.7	0.4	0.3	-14.2	2.4	-11.8

% of Loss Defor.	Degrad.	Fragm.	% of Gain Affor.	Amelior	Manm.
52.7	21.4	25.9	70.8	18.0	11.1

COMPARISON OF AREA CHANGES AND BIOMASS CHANGES

Natural Forest	tot 1990	tot 1980
Area ('000 ha)	1952.7	2088.4
% Forest/Land	70.1	75.0
Biomass/Ha (Tons)	103.8	103.0

	AREA CHANGES '000 Ha	%	BIOMASS CHANGES Million Tons	% of Total Biomass	% of Fores Biomass
Net Deforestation	136.0	6.5	-9.4	-4.2	-4.4
Net Forest Degradation	40.0	1.4	-2.6	-1.2	-1.2

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[3] Biomass changes related to Manmade Woody Vegetation of historical image are not accounted under these headings.

[4] Inclusive of biomass changes in Manmade Woody Vegetation

ANNEX 12
(Section 4.2.1)

Analysis of Pan-Tropical Change Matrix[1]

Number of Sampling Units:	115[2]	Land area studied[3] :	(million hectares)	251.33
Results expanded to the total land area of the sampling frame		:	(million hectares)	3068.01

RESULTS BY LAND COVER CATEGORIES[4]

1) Changes in CONTINUOUS NATURAL FOREST LAND

Classes: Closed Forest Open Forest Long Fallow

	Conv. to Manm. W. Veg	Amelioration	Unchanged	Degradat.	Fragment. (partial defor.)	Deforestation To Other Wooded	Deforestation To Non Wooded	Total Cont. Forest land 1980
Change '000ha	4174.6	2219.9	1607829.9	19547.3	15441.6	31104.8	49117.8	1729435.9
Change Rate %	0. 2	0. 1		1.1	0. 9	1.8	2.8	

2) Changes in FRAGMENTED NATURAL FOREST LAND

Class Fragmented Forest; composed by a mosaic of Forest / Non-Forest. **Estimated Forest Fraction :** 0.33

	Conv. to Manm. W. Veg	Natural Affor.	Unchanged	(Partial deforest.) To Other Wooded	(Partial deforest.) To Non Wooded	Tot.Fragm. For. Land 1980
Change '000ha	391.7	1838.2	159328.1	1853.1	11652.0	175063.0
Change Rate %	0. 2	1.0		1.1	6.7	

Estimated area and changes of ACTUAL forest area within "Fragmented Forest" Class:

	net area	net aff.	Unch.forest	(Net deforestation)		Net Forest
Change '000ha	262.4	1231.6	52578.3	611.5	3845.2	57770.8
Change Rate %	0. 5	2.1		1.1	6.7	

3) Changes in OTHER WOODED LAND

Classes: Shrubs, Short Fallow

	Conv. to Manm. W. Veg	Natural afforestation Cont.	Natural afforestation Fragm.	Amelioration	Unchanged	Degradation moderate	Degradation complete	Total Other Wood.Land 1980
Change '000ha	324.2	1925.9	525.3	335.5	272481.6	162.4	26848.5	302603.3
Change Rate %	0. 1	0. 6	0. 2	0. 1		0. 1	8.9	

4) Changes in NON WOODED AREAS

Classes: Other Land Cover, Water

	Conv. to Manm. W. Veg	Natural afforestation Cont.	Natural afforestation Fragm.	Amelioration	Unchanged	Total Non Wood.Area 1980
Change '000ha	462.4	1848.2	1399.1	4053.3	837271.9	845034.9
Change Rate %	0. 1	0. 2	0. 2	0. 5		

5) Changes of MANMADE WOODY VEGETATION

Class Manmade Woody Vegetation (inclusive of both forest and agricultural plantations)

	Tot.New MWVeg (Recent Image)	New Manmade Woody Veg. Created On Previous: Forest Land	Other W. Land	Non W. Areas	Unchanged	Changed To: Cont.or Fragm. Forest	Other Wooded	Non Wooded	Tot Manm. WoodyVeg 1980
Change '000ha	5352.8	4566.2	324.2	462.4	15680.9	71.4	12.8	110.0	15875.2
Change Rate %	33.7	28.8	2.0	2.9		0. 4	0. 1	0. 7	

[1] The Pan-tropical Change Matrix and Woody Biomass Flux Diagramis are presented and discussed in Chapter 4.2.1

[2] For 2 sampling units out of 117 the change matrix could not be produced due to lack of suitable satellite images.

[3] Results based on **visible common land area** between recent and historical satellite images.

[4] All estimated **area changes** and **percentage change rates** refer to the 10 year period 1980-1990. The terms used are discussed in Section 2.2.1: "Definition of forest and forest area changes. The symbol "ε" indicates values below the displayed decimal point.

Analysis of **Pan-Tropical** Change Matrix (All regions, all ecological zones)

SUMMARY OF AREA RESULTS

6) Gross Deforestation (loss of natural forest)

Tot Gross Deforestation	'000 ha	99329.0
Gross Deforestation Rate	%	5.6

7) Net Deforestation (loss - gain of natural forest)

Tot Net Deforestation	'000 ha	93616.9
Net Deforestation Rate	%	5.2

8) Net Degradation Of Natural Forest

Tot Net For. Degradation	'000 ha	17327.4
Net Forest Degradat.Rate	%	1.0

9) Net Degradation Of Natural Woody Vegetation

Tot Net Degradation	'000 ha	39949.5
Net Degradation Rate	%	1.9

10) BALANCE NATURAL FOREST - MANMADE WOODY VEGETATION

		Natural Forest Continuous & Fragmented	**Manmade Woody Vegetation**	**Total Natural + Manmade**
Area at year 1980	'000 ha	1787207	15875	1803082
Area at year 1990	'000 ha	1693590	21034	1714624
Difference	'000 ha	-93617	5159	-88458
Change Rate	%	-5.2	32.5	-4.9
Annual simple rate	%	-0.52	3.25	-0.49

INDICATIVE ESTIMATES OF BIOMASS CHANGES

					Biomass in Million Tons								
	Estim.ed Biomass '000 T/ha	Classes 1990 Biomass 1990	Classes 1980 Biomass 1990	Classes 1980 Biomass 1980	Loss [1]			Gain [5]			Total	Total	Net
					Defor.	Degrad.	Fragm.	Affor.	Amelior	Manm.	Loss [2]	Gain [6]	**Balance**
Closed Forest	0.225	288013	290636	307790	-13549	-2525	-1525	-	-	444	-17598	444	**-17154**
Open forest	0.090	26497	26328	27445	-1066	-9	-162	-	115	5	-1237	120	**-1116**
Long fallow	0.083	5068	4506	4712	-337	-	-27	-	158	ε	-364	158	**-206**
Fragm.Forest	0.059	10382	9784	10286	-654	-	-	131	-	21	-654	152	**-501**
Shrubs	0.040	6401	6352	6932	-	-644	-	52	-	11	-644	63	**-580**
Short Fallow	0.030	4499	3883	3879	-	-174	-	162	2	14	-174	178	**4**
Oth.Land Cov.	0.007	6446	6353	5903	-	-11	-	304	111	47	-11	461	**450**
Water			52		-	-	-	37	13	2		52	**52**
Manm.W.Veg	0.113	2366	1778	1786	-	-	-	-	-	-	-22	14	**-8**
Total Biomass		349673	349673	368732	-15606	-3361	-1714	686	398	545	-20703	1643	**-19060**

% of Loss [5]			% of Gain [5]		
Defor.	Degrad.	Fragm.	Affor.	Amelior	Manm.
75.4	16.2	8.3	41.8	24.2	33.2

COMPARISON OF AREA CHANGES AND BIOMASS CHANGES

Natural Forest	tot 1990	tot 1980
Area ('000 ha)	1693589.8	1787206.7
% Forest/Land	55.3	58.3
Biomass/Ha (Tons)	195.6	196.0

	AREA CHANGES		**BIOMASS CHANGES**		
	'000 Ha	%	Million Tons	% of Total Biomass	% of Forest Biomass
Net Deforestation	-93616.6	-5.2	-16633.2	-4.5	-4.7
Net Forest Degradation	-17327.4	-1.0	-2259.9	-0.6	-0.6

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[1] Biomass changes related to 1980 Manmade Woody Vegetation are not accounted under these headings.

[2] Inclusive of biomass changes in Manmade Woody Vegetation

ANNEX 13

Africa Region

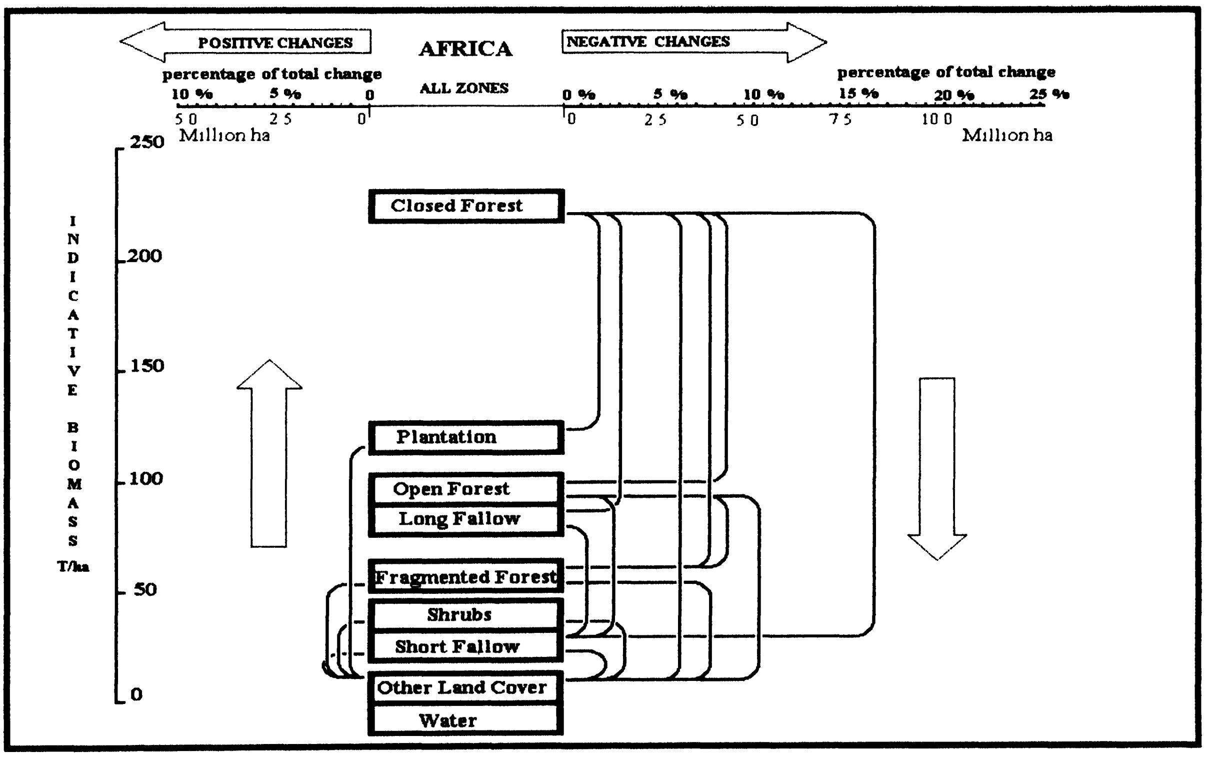
Regional level transition matrix and flux diagram (Section 4.2.2)

Number of Sampling Units:	47	Land area studied (million ha):	104.24
Results expanded to the total land area surveyed (stratum 1, 2, 3; million hectares):			1223.96

Area transition matrix for the standard period 1980-1990[1]

Classes at year 1980	Classes at year 1990 (Million hectares)									TOTAL 1980	
	Closed Forest	**Open Forest**	**Long Fallow**	**Frag-mented Forest**	**Shrub**	**Short Fallow**	**Other Land Cover**	**Water**	**Planta-tions**	**Million ha**	**%**
Closed Forest	**324.37**	4.48	1.59	4.01	0.10	8.47	3.26	ε	1.02	**347.32**	***28.4***
Open Forest	0.31	**175.53**	0.46	4.62	0.13	1.49	5.91	ε	0.05	**188.49**	***15.4***
Long Fallow	0.18	0.13	**7.88**	0.02	0.04	0.65	0.27	0.01	ε	**9.19**	***0.8***
Fragm.Forest	0.28	0.49	0.01	**111.82**	0.08	0.11	4.02	0.01	ε	**116.82**	***9.5***
Shrubs	0.01	0.10	ε	0.03	**56.33**		1.77	ε		**58.24**	***4.8***
Short Fallow	0.21	0.11	0.10	0.02	ε	**68.01**	1.22	0.01	0.07	**69.75**	***5.7***
Other Land	0.22	0.52	0.10	1.15	0.84	1.26	**426.63**	0.53	0.19	**431.45**	***35.3***
Water	0.01	ε		ε	0.01	0.05	0.88	**(water)**		**0.95**	***0.1***
Plantation	0.01	ε	ε	ε	ε	ε	0.03	ε	**1.69**	**1.73**	***0.1***
TOT 1990 M.ha	**325.60**	**181.37**	**10.14**	**121.67**	**57.53**	**80.05**	**444.00**	**0.56**	**3.03**	**1223.96**	
%	***26.6***	***14.8***	***0.8***	***9.9***	***4.7***	***6.5***	***36.3***	ε	***0.2***		***100***

Woody Biomass Flux Diagram[2]



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[1] Results based on visible common area between recent and historical satellite images. Stable water (ocean, sea, lakes, rivers) has been excluded from the analysis of changes. The symbol "ε" indicates values below the displayed decimal point.

[2] Only class transitions accounting for more than 2 percent of the total change are shown in the diagram.

ANNEX 14

Latin America Region

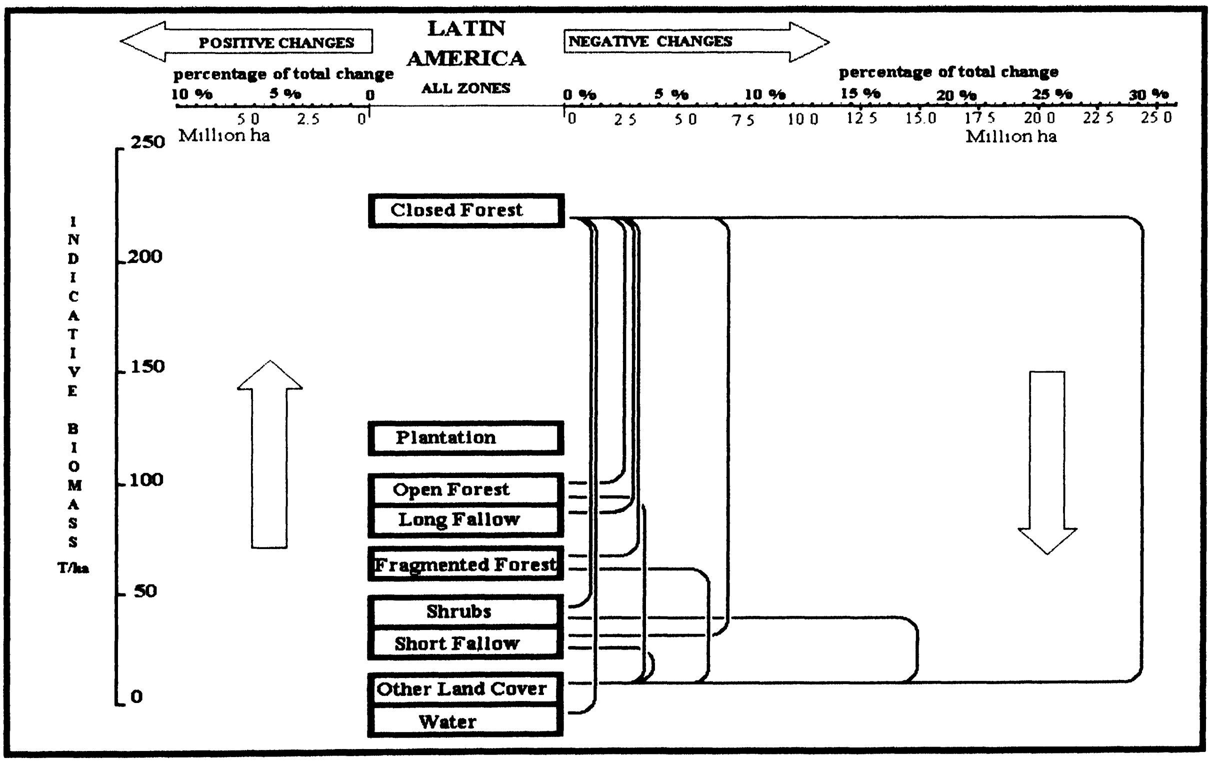
Regional level transition matrix and flux diagram (Section 4.2.2)

Number of Sampling Units:	39	Land area studied (million ha):	87.83
Results expanded to the total land area surveyed (stratum 1, 2, 3; million hectares):			1233.56

Area transition matrix for the standard period 1980-1990[1]

Classes at year 1980	Classes at year 1990 (Million hectares) Closed Forest	Open Forest	Long Fallow	Frag-mented Forest	Shrub	Short Fallow	Other Land Cover	Water	Planta-tions	TOTAL 1980 Million ha	%
Closed Forest	**742.09**	2.59	3.11	3.16	1.24	6.92	24.37	1.44	0.04	**784.97**	***63.6***
Open Forest	0.12	**81.54**	0.17	0.30	0.77	0.57	3.45	0.03	0.08	**87.03**	***7.1***
Long Fallow	0.12	0.11	**5.63**		0.10	1.00	0.14	0.01	ε	**7.11**	***0.6***
Fragm.Forest	0.07	0.01	0.32	**32.81**	0.09	0.72	6.15	0.23	0.24	**40.63**	***3.3***
Shrubs	0.04	0.02	0.12	0.01	**85.89**	0.19	14.99	0.07	0.12	**101.45**	***8.2***
Short Fallow	0.11	0.01	0.22	0.08	0.04	**13.91**	3.78	0.14	ε	**18.29**	***1.5***
Other Land	0.21	0.02	0.01	0.09	0.85	0.14	**189.54**	0.87	0.09	**191.83**	***15.6***
Water	0.11	0.01	0.01	0.04	ε	0.02	0.47	**(water)**	ε	**0.66**	***0.1***
Plantation							0.01		**1.57**	**1.59**	***0.1***
TOT 1990 M.ha	**742.87**	**84.32**	**9.60**	**36.49**	**88.98**	**23.46**	**242.89**	**2.79**	**2.15**	**1233.56**	
%	***60.2***	***6.8***	***0.8***	***3.0***	***7.2***	***1.9***	***19.7***	***0.2***	***0.2***		***100***

Woody Biomass Flux Diagram[2]



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[1] Results based on visible common area between recent and historical satellite images. Stable water (ocean, sea, lakes, rivers) has been excluded from the analysis of changes. The symbol "ε" indicates values below the displayed decimal point.

[2] Only class transitions accounting for more than 2 percent of the total change are shown in the diagram.

ANNEX 15

Asia Region

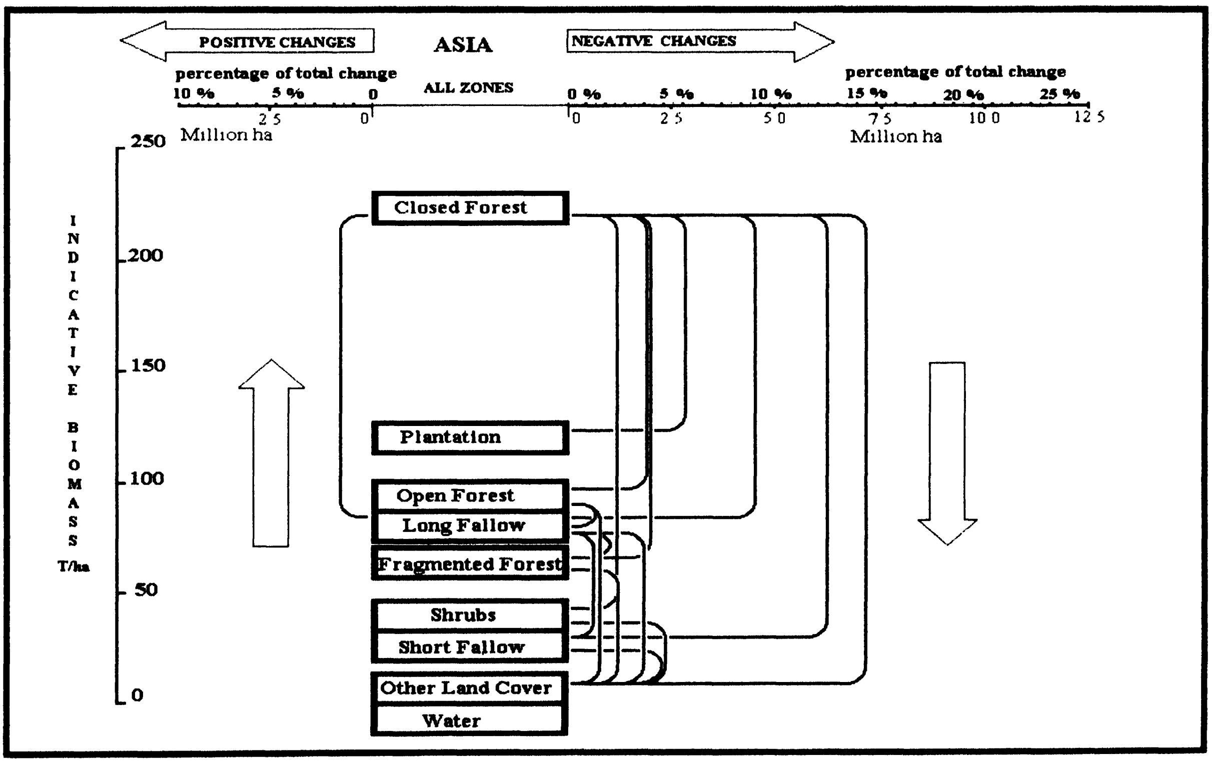
Regional level transition matrix and flux diagram (Section 4.2.2)

Number of Sampling Units:	29	Land area studied (million ha):	59.26
Results expanded to the total land area surveyed (stratum 1, 2, 3; million hectares):			610.49

Area transition matrix for the standard period 1980-1990[1]

Classes at year 1980	Closed Forest	Open Forest	Long Fallow	Fragmented Forest	Shrub	Short Fallow	Other Land Cover	Water	Plantations	TOTAL 1980 Million ha	TOTAL 1980 %
	Classes at year 1990 (Million hectares)										
Closed Forest	**209.44**	1.90	4.57	2.00	1.19	6.18	7.16	0.33	2.88	**235.66**	***38.6***
Open Forest	0.43	**26.23**	0.68	0.26	0.56	0.34	0.82	0.02	0.08	**29.41**	***4.8***
Long Fallow	0.80	0.02	**35.09**	1.07	0.65	0.70	1.86	0.04	0.01	**40.24**	***6.6***
Fragm.Forest	0.22	0.14	0.30	**14.70**	0.28	0.58	1.23	0.01	0.15	**17.61**	***2.9***
Shrubs	0.10	0.08	0.14	0.11	**10.47**	0.15	2.42	0.11	0.03	**13.60**	***2.2***
Short Fallow	0.24	0.17	0.15	0.28	0.12	**37.86**	2.30	0.04	0.10	**41.26**	***6.8***
Other Land	0.29	0.16	0.15	0.11	0.25	0.63	**218.05**	0.18	0.16	**219.98**	***36.0***
Water	0.02	0.01		0.01		ε	0.11	**(water)**	0.02	**0.16**	***0.0***
Plantation	0.04	0.03	ε	ε		0.01	0.07		**12.41**	**12.56**	***2.1***
TOT 1990 M.ha	**211.58**	**28.73**	**41.07**	**18.53**	**13.51**	**46.45**	**234.02**	**0.74**	**15.85**	**610.49**	
%	*34.7*	*4.7*	*6.7*	*3.0*	*2.2*	*7.6*	*38.3*	*0.1*	*2.6*		***100***

Woody Biomass Flux Diagram[2]



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[1] Results based on visible common area between recent and historical satellite images. Stable water (ocean, sea, lakes, rivers) has been excluded from the analysis of changes. The symbol "ε" indicates values below the displayed decimal point.
[2] Only class transitions accounting for more than 2 percent of the total change are shown in the diagram.

ANNEX 16
(Section 4.2.3)

Summary table of the main parameters characterizing the ecological zones

Ecological zone	Dominant forest formations	Bioclimatic parameters Mean annual rainfall (mm)	No. of rainy days (length of dry season)	Mean annual air humidity (%)	Mean annual temperature (°C)	Mean temperature of coldest month (°C)
Zone 1 **Wet and Very Moist**	Wet and very moist evergreen and semi-evergreen forest	>2000	>150 (no distinct dry season)	>75	22-27	>23
Zone 2 **Moist** (with short and long dry season)	Moist semi-deciduous and deciduous forest, woodlands, and tree savanna	1000-2000	70-170 (2-7 months)	>65	22-27	>23
Zone 3 **Sub-Dry to Very Dry**	Drought-deciduous and evergreen forests, woodlands, tree savanna; discontinuous thickets, tree/shrub savanna	200-1000	20-120 (7-11 months)	~50	20-30	>15
Semi-arid and Arid zones (not represented within the sampling frame)	Tree/shrub steppe	<200	<20 (12 months)	<50	14-25	>10

ANNEX 17

Wet and Very Moist Zone

(all regions)

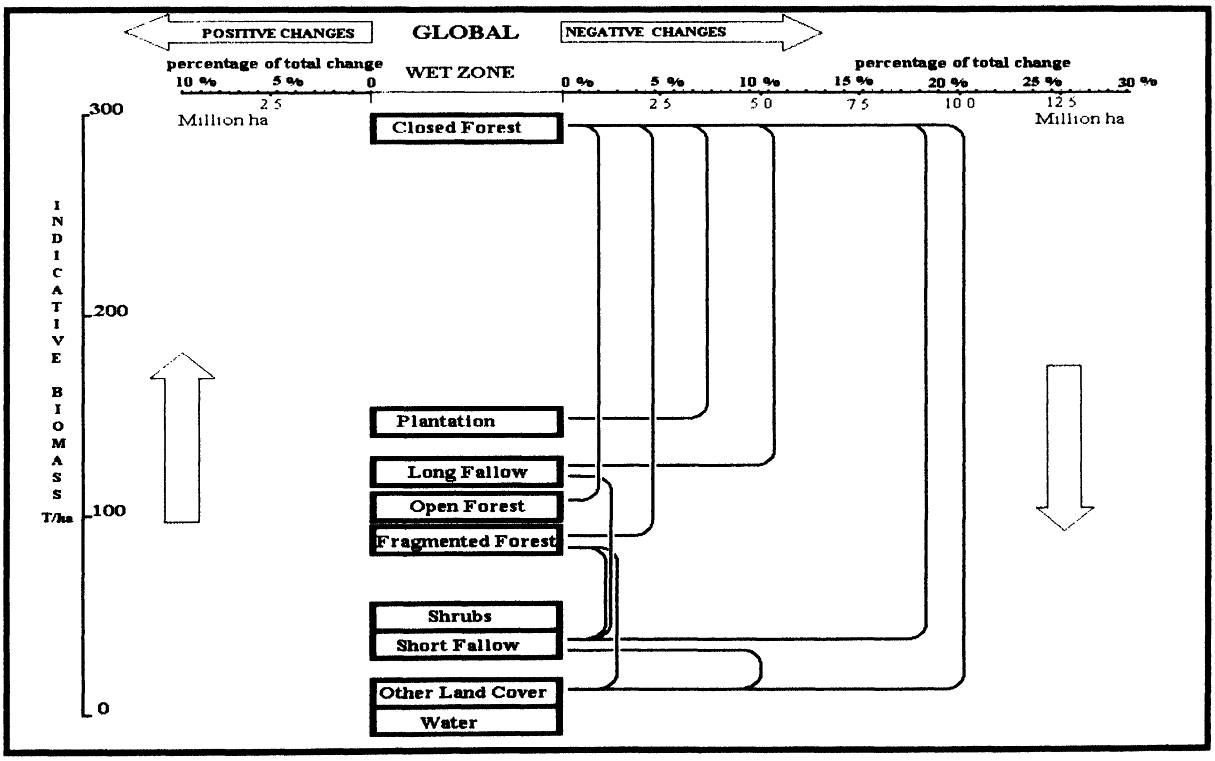
Eecological level transition matrix and flux diagram (Section 4.2.3)

Number of Sampling Units:	26	Land area studied (million ha):	45.54
Results expanded to the total land area surveyed (stratum 1, 2, 3; million hectares):			891.76

Area transition matrix for the standard period 1980-1990[1]

	Classes at year 1990 (Million hectares)									TOTAL 1980	
Classes at year 1980	Closed Forest	Open Forest	Long Fallow	Frag-mented Forest	Shrub	Short Fallow	Other Land Cover	Water	Planta-tions	Million ha	%
Closed Forest	**685.36**	0.96	5.35	2.32	0.42	9.16	10.11	0.36	3.70	**717.74**	***80.5***
Open Forest	0.10	**11.54**	0.02	0.08	0.01	0.36	0.20	0.01	0.02	**12.32**	***1.4***
Long Fallow	0.37	0.06	**21.63**	0.06	0.13	1.31	0.47	0.01	ε	**24.02**	***2.7***
Fragm.Forest	0.07	0.03	0.33	**7.78**	0.19	1.22	1.44	0.05	0.14	**11.24**	***1.3***
Shrubs	ε		0.04	0.01	**3.52**	0.03	0.20	ε	0.01	**3.81**	***0.4***
Short Fallow	0.27	0.04	0.27	0.22	0.02	**55.78**	5.04	0.13	0.14	**61.92**	***6.9***
Other Land	0.13	0.01	0.03	0.02	0.64	0.62	**47.32**	0.09	0.05	**48.93**	***5.5***
Water	0.11	ε	0.01	0.03		0.02	0.13	**(water)**	0.01	**0.29**	ε
Plantation	ε	ε	ε			0.01	0.02		**11.45**	**11.48**	***1.3***
TOT 1990 M.ha	**686.41**	**12.65**	**27.68**	**10.52**	**4.93**	**68.50**	**64.92**	**0.66**	**15.50**	**891.76**	
%	***77.0***	***1.4***	***3.1***	***1.2***	***0.6***	***7.7***	***7.3***	***0.1***	***1.7***		***100***

Woody Biomass Flux Diagram[2]



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[1] Results based on visible common area between recent and historical satellite images. Stable water (ocean, sea, lakes, rivers) has been excluded from the analysis of changes. The symbol "ε" indicates values below the displayed decimal point.

[2] Only class transitions accounting for more than 2 percent of the total change are shown in the diagram.

ANNEX 18

Moist Zone with short and long dry season

(all regions)

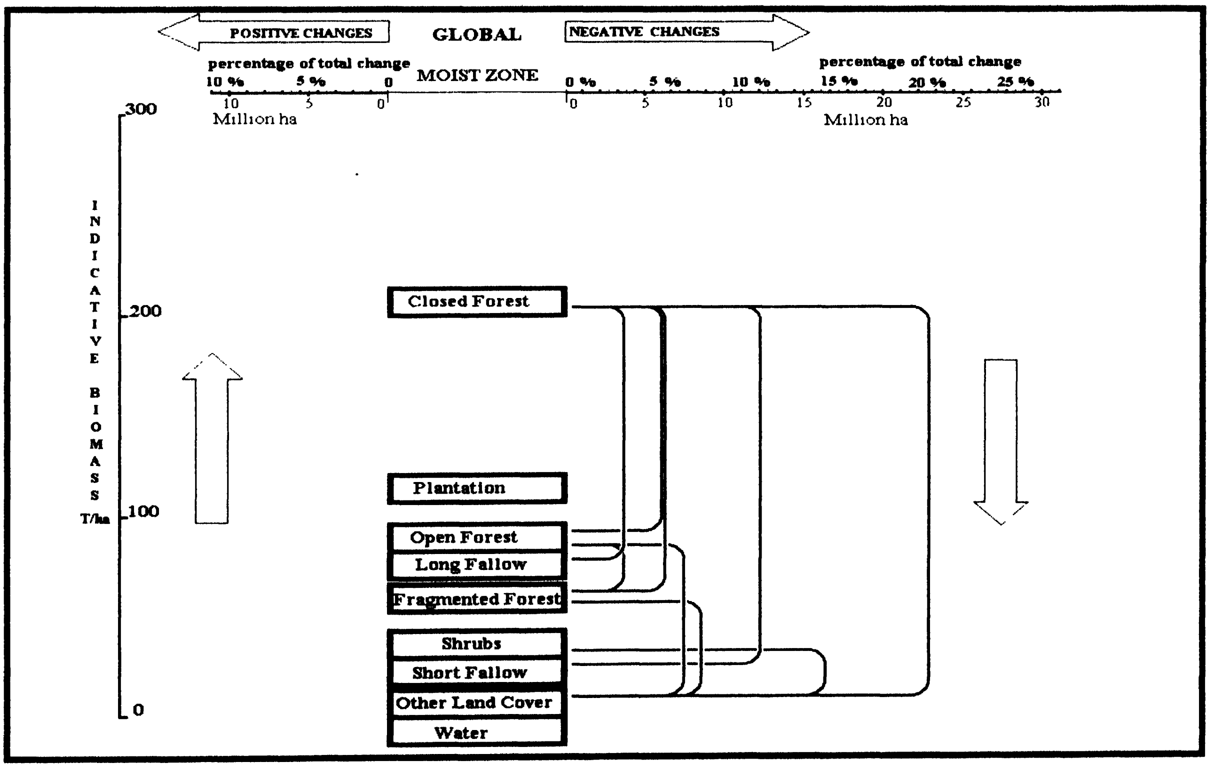
Eecological level transition matrix and flux diagram (Section 4.2.3)

Number of Sampling Units:	60	Land area studied (million ha):	136.88
Results expanded to the total land area surveyed (stratum 1, 2, 3; million hectares):			1469.41

Area transition matrix for the standard period 1980-1990[1]

Classes at year 1980	Classes at year 1990 (Million hectares) Closed Forest	Open Forest	Long Fallow	Frag-mented Forest	Shrub	Short Fallow	Other Land Cover	Water	Planta-tions	TOTAL 1980 Million ha	%
Closed Forest	**484.65**	6.09	3.66	6.17	1.59	12.30	22.91	1.14	0.21	**538.71**	***36.7***
Open Forest	0.61	**147.50**	0.65	3.75	1.16	1.43	7.60	0.03	0.16	**162.88**	***11.1***
Long Fallow	0.73	0.14	**21.37**	1.03	0.62	1.00	1.62	0.04	0.01	**26.55**	***1.8***
Fragm.Forest	0.33	0.29	0.30	**120.23**	0.22	0.17	8.62	0.19	0.24	**130.59**	***8.9***
Shrubs	0.14	0.08	0.22	0.09	**98.88**	0.31	16.42	0.13	0.14	**116.40**	***7.9***
Short Fallow	0.23	0.16	0.12	0.15	0.14	**58.48**	1.88	0.06	0.04	**61.26**	***4.2***
Other Land	0.49	0.33	0.22	1.12	0.35	1.38	**424.06**	0.94	0.34	**429.21**	***29.2***
Water	0.02	0.02	ε	0.01	0.01	0.05	0.51	**(water)**	ε	**0.62**	ε
Plantation	0.04	0.02	ε	ε	ε	ε	0.07	ε	**3.06**	**3.20**	***0.2***
TOT 1990 M.ha	**487.25**	**154.61**	**26.52**	**132.55**	**102.96**	**75.11**	**483.68**	**2.52**	**4.20**	**1469.41**	
%	***33.2***	***10.5***	***1.8***	***9.0***	***7.0***	***5.1***	***32.9***	***0.2***	***0.3***		***100***

Woody Biomass Flux Diagram[2]



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[1] Results based on visible common area between recent and historical satellite images. Stable water (ocean, sea, lakes, rivers) has been excluded from the analysis of changes. The symbol "ε" indicates values below the displayed decimal point.

[2] Only class transitions accounting for more than 2 percent of the total change are shown in the diagram.

ANNEX 19

Sub-Dry to Very Dry Zone

(all regions)

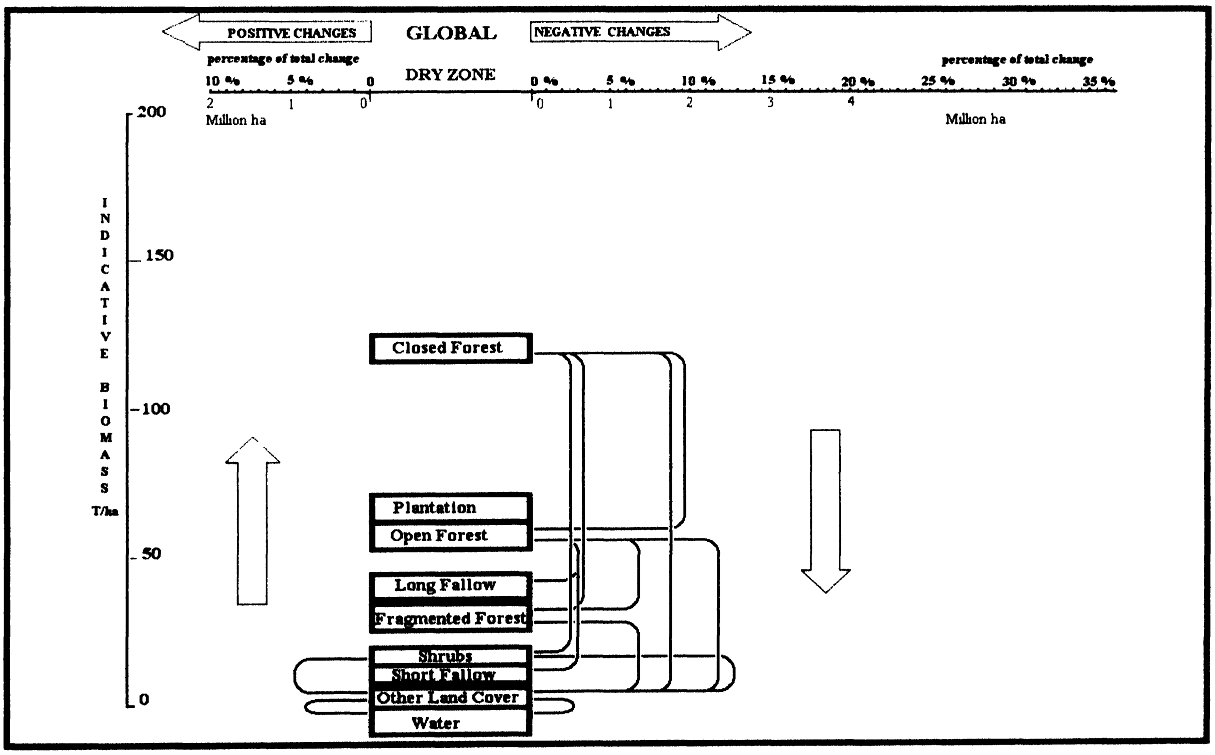
Eecological level transition matrix and flux diagram (Section 4.2.3)

Number of Sampling Units:	29	Land area studied (million ha):	68.91
Results expanded to the total land area surveyed (stratum 1, 2, 3; million hectares):			706.84

Area transition matrix for the standard period 1980-1990[1]

	Classes at year 1990 (Million hectares)									TOTAL 1980	
Classes at year 1980	Closed Forest	Open Forest	Long Fallow	Frag-mented Forest	Shrub	Short Fallow	Other Land Cover	Water	Planta-tions	Million ha	%
Closed Forest	**105.90**	1.93	0.26	0.68	0.53	0.12	1.77	0.28	0.05	**111.51**	***15.8***
Open Forest	0.15	**124.27**	0.64	1.36	0.29	0.62	2.37	0.02	0.03	**129.74**	***18.4***
Long Fallow	0.01	0.07	**5.61**		0.04	0.05	0.18	ε		**5.96**	***0.8***
Fragm.Forest	0.18	0.32	ε	**31.32**	0.04	0.02	1.35	ε	0.01	**33.23**	***4.7***
Shrubs	0.01	0.12	0.01	0.04	**50.29**	ε	2.56	0.05	0.01	**53.10**	***7.5***
Short Fallow	0.05	0.08	0.07	0.01	ε	**5.53**	0.38	ε		**6.13**	***0.9***
Other Land	0.10	0.36	0.01	0.21	0.95	0.03	**362.84**	0.56	0.05	**365.12**	***51.7***
Water	0.01	ε		0.01	ε		0.82	**(water)**	0.01	**0.86**	***0.1***
Plantation	ε			ε		ε	0.02		**1.17**	**1.20**	***0.2***
TOT 1990 M.ha	**106.40**	**127.15**	**6.61**	**33.62**	**52.14**	**6.37**	**372.31**	**0.92**	**1.33**	**706.84**	
%	***15.1***	***18.0***	***0.9***	***4.8***	***7.4***	***0.9***	***52.7***	***0.1***	***0.2***		***100***

Woody Biomass Flux Diagram[2]



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[1] Results based on visible common area between recent and historical satellite images. Stable water (ocean, sea, lakes, rivers) has been excluded from the analysis of changes. The symbol "ε" indicates values below the displayed decimal point.

[2] Only class transitions accounting for more than 2 percent of the total change are shown in the diagram.

ANNEX 20

Summary Table of Forest Cover Changes at Eco-Regional Level

Pan-tropical

Parameters	Wet and Very Moist		Moist		Sub-Dry to Very Dry		All Zones	
	'000 ha	%	'000 ha	%	'000 ha	%	'000 ha	%
Tropical land area	975156		1886322		2083640		4945118	
Land area studied (sampling frame)[1]	891756	*91.4*	1469412	*77.9*	706844	*33.9*	3068012	*62.0*
Estimated forest area (F3)[2] 1980	757794	*85.0*	771237	*52.5*	258176	*36.5*	1787207	*58.3*
Forest area changed 1980-1990	36555.9	*4.8*	77739.7	*10.1*	11896.4	*4.6*	126192.0	*7.1*
Types of forest area changes								
Deforested to non-wooded	11650.8	*31.9*	36241.1	*46.6*	5071.1	*42.6*	52963.0	*42.0*
Deforested to other wooded	11836.9	*32.4*	18221.0	*23.4*	1658.4	*13.9*	31716.3	*25.1*
Total Deforested	**23487.7**	***64.3***	**54462.1**	***70.1***	**6729.5**	***56.6***	**84679.3**	***67.1***
Fragmented (partial deforestation)	2456.4	*6.7*	10950.0	*14.1*	2035.2	*17.1*	15441.6	*12.2*
Degraded	6332.9	*17.3*	10387.8	*13.4*	2826.6	*23.8*	19547.3	*15.5*
Ameliorated	521.6	*1.4*	1475.3	*1.9*	223.0	*1.9*	2219.9	*1.8*
Converted to Plantation	3757.3	*10.3*	464.4	*0.6*	82.1	*0.7*	4303.8	*3.4*

In view of the limited number of sampling units available for each ecological zone within each region the following results should be considered as preliminary and indicative of main trends.

Africa

Parameters	Wet and Very Moist		Moist		Sub-Dry to Very Dry		All Zones	
	'000 ha	%	'000 ha	%	'000 ha	%	'000 ha	%
Tropical land area	123189		827959		1376868		2328016	
Land area studied (sampling frame)[1]	112551	*91.4*	741004	*89.5*	370402	*26.9*	1223957	*52.6*
Estimated forest area (F3)[2] 1980	91020	*80.9*	363235	*49.0*	129301	*34.9*	583556	*47.7*
Forest area changed 1980-1990	3759.8	*4.1*	29049.2	*8.0*	5798.7	*4.5*	38607.7	*6.6*
Types of forest area changes								
Deforested to non-wooded	52.4	*1.4*	8182.3	*28.2*	2548.4	*43.9*	10783.1	*27.9*
Deforested to other wooded	1984.0	*52.8*	8088.5	*27.8*	880.4	*15.2*	10952.9	*28.4*
Total Deforested	**2036.4**	***54.2***	**16270.8**	***56.0***	**3428.8**	***59.1***	**21736.0**	***56.3***
Fragmented (partial deforestation)	93.3	*2.5*	7067.3	*24.3*	1488.2	*25.7*	8648.9	*22.4*
Degraded	713.7	*19.0*	5025.4	*17.3*	790.0	*13.6*	6529.0	*16.9*
Ameliorated	28.0	*0.7*	504.5	*1.7*	91.7	*1.6*	624.2	*1.6*
Converted to Plantation	888.4	*23.6*	181.2	*0.6*	0.0	*0.0*	1069.6	*2.8*

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[1] All satellite images with more than one million hectares of land and more than ten percent of forest. See Section 4.2.3 for sampling intensities by ecological zone and geographic region.

[2] F3 forest definition = Closed forest, Open forest, Long fallow and Fragmented forest (see also Section 2.2.1).

Latin America

Parameters	Wet and Very Moist		Moist		Sub-Dry to Very Dry		All Zones	
	'000 ha	%	'000 ha	%	'000 ha	%	'000 ha	%
Tropical land area	527714		817640		343036		1688389	
Land area studied (sampling frame)[1]	521604	*98.8*	532485	*65.1*	179475	*52.3*	1233564	*73.1*
Estimated forest area (F3)[2] 1980	499667	*95.8*	307204	*57.7*	85652	*47.7*	892522	*72.4*
Forest area changed 1980-1990	15875.0	*3.2*	34214.6	*11.1*	2201.7	*2.6*	52291.3	*5.9*
Types of forest area changes								
Deforested to non-wooded	7774.6	*49.0*	23257.6	*68.0*	508.7	*23.1*	31540.9	*60.3*
Deforested to other wooded	3735.6	*23.5*	6878.9	*20.1*	246.1	*11.2*	10860.6	*20.8*
Total Deforested	**11510.3**	***72.5***	**30136.4**	***88.1***	**754.7**	***34.3***	**42401.4**	***81.1***
Fragmented (partial deforestation)	1287.9	*8.1*	1926.1	*5.6*	247.7	*11.3*	3461.8	*6.6*
Degraded	2851.8	*18.0*	1874.6	*5.5*	1148.0	*52.1*	5874.4	*11.2*
Ameliorated	220.3	*1.4*	77.2	*0.2*	51.3	*2.3*	348.8	*0.7*
Converted to Plantation	4.7	*0.0*	200.3	*0.6*	0.0	*0.0*	205.0	*0.4*

Asia

Parameters	Wet and Very Moist		Moist		Sub-Dry to Very Dry		All Zones	
	'000 ha	%	'000 ha	%	'000 ha	%	'000 ha	%
Tropical land area	324253		240723		363736		928712	
Land area studied (sampling frame)[1]	257601	*79.4*	195923	*81.4*	156967	*43.2*	610491	*65.7*
Estimated forest area (F3)[2] 1980	167107	*64.9*	100798	*51.4*	43223	*27.5*	311129	*51.0*
Forest area changed 1980-1990	16921.0	*10.1*	14475.9	*14.4*	3896.1	*9.0*	35293.0	*11.3*
Types of forest area changes								
Deforested to non-wooded	3823.8	*22.6*	4801.2	*33.2*	2014.0	*51.7*	10639.0	*30.1*
Deforested to other wooded	6117.2	*36.2*	3253.6	*22.5*	532.0	*13.7*	9902.9	*28.1*
Total Deforested	**9941.0**	***58.7***	**8054.8**	***55.6***	**2546.0**	***65.3***	**20541.9**	***58.2***
Fragmented (partial deforestation)	1075.1	*6.4*	1956.6	*13.5*	299.3	*7.7*	3330.9	*9.4*
Degraded	2767.4	*16.4*	3487.9	*24.1*	888.7	*22.8*	7143.9	*20.2*
Ameliorated	273.3	*1.6*	893.7	*6.2*	80.0	*2.1*	1247.0	*3.5*
Converted to Plantation	2864.2	*16.9*	83.0	*0.6*	82.1	*2.1*	3029.3	*8.6*

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[1] All satellite images with more than one million hectares of land and more than ten percent of forest. See Section 4.2.3 for sampling intensities by ecological zone and geographic region.

[2] F3 forest definition = Closed forest, Open forest, Long fallow and Fragmented forest (see also Section 2.2.1).

FAO TECHNICAL PAPERS

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1 Forest utilization contracts on public land, 1977 (E F S)
2 Planning forest roads and harvesting systems, 1977 (E F S)
3 World list of forestry schools, 1977 (E/F/S)
3 Rev.1 World list of forestry schools, 1981 (E/F/S)
3 Rev.2 World list of forestry schools, 1986 (E/F/S)
4/1 World pulp and paper demand, supply and trade 1- Vol. 1, 1977 (E F S)
4/2 World pulp and paper demand, supply and trade – Vol. 2, 1977 (E F S)
5 The marketing of tropical wood in South America, 1976 (E S)
6 National parks planning, 1976 (E F S**)
7 Forestry for local community development, 1978 (Ar E F S)
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9 Wood chips – production, handling, transport, 1976 (C E S)
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17 Sup.2 Economic analysis of forestry projects: readings, 1980 (C E)
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19/2 Pulping and paper-making properties of fast-growing plantation wood species – Vol. 2, 1980 (E)
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